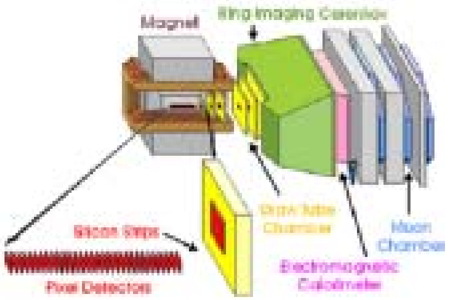


BTeV

S. Stone

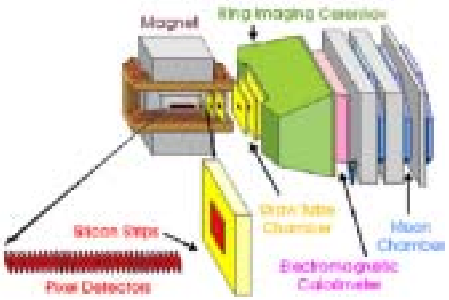
March 26, 2003

Now: The Physics Case,

Sensitivities

& Comparisons

Next: The detector, R&D, schedule & costs



Collaboration

Origins: Fnal FT CLEO Hera/HeraB

Massive expertise in pixels, trigger, electronics, tracking, crystal calorimetery, RICH, & Muon detection

Belarussian State- D .Drobychev, A. Lobko, A. Lopatrik, R. Zouversky

UC Davis - P. Yager

Univ. of Colorado-J. Cumalat, P. Rankin, K. Stenson

Fermi National Lab
J. Appel, E. Barsotti, C. N. Brown , J. Butler, H. Cheung, D. Christian, S. Cihangir, I. Gaines, P. Garbincius, L. Garren, E. Gottschalk, G. Jackson, A. Hahn, P. Kasper, P. Kasper, R. Kutschke, S. Kwan, P. Lebrun, P. McBride, J. Slaughter, M. Votava, M. Wang, J. Yarba

Univ. of Florida at Gainesville
P. Avery

University of Houston
A. Daniel, K. Lau, M. Ispiryan, B. W. Mayes, V. Rodriguez, S. Subramania, G. Xu

Illinois Institute of Technology
R. A. Burnstein, D. M. Kaplan, L. M. Lederman, H. A. Rubin, C. White

Univ. of Illinois- M. Haney, D. Kim, M. Selen, V. Simaitis, J. Wiss

Univ. of Insubria in Como-
P. Ratcliffe, M. Rovere

INFN - Frascati- M. Bertani, L. Benussi, S. Bianco, M. Caponero, F. Fabbri, F. Felli, M. Giardoni, A. La Monaca, E. Pace, M. Pallotta, A. Paolozzi

INFN - Milano - G. Alimonti, M.Dinardo, L. Edera, D. Lunesu, S.Magni, D. Menasce, L. Moroni, D. Pedrini, S.Sala, L. Uplegger

INFN - Pavia- G. Boca, G. Cosssali, G. Liguori, F.Manfredi, M. Manghisoni, M. Marengo, L. Ratti, V. Re, M. Santini, V. Speziali, P. Torre, G. Traversi

IHEP Protvino, Russia
A. Derevschikov, Y. Goncharenko, V. Khodyrev, V. Kravtsov, A. Meschanin, V. Mochalov, D. Morozov, L. Nogach, K. Shestermanov, L. Soloviev, A. Uzunian, A. Vasiliev

University of Iowa
C. Newsom, & R. Braunger

University of Minnesota
J. Hietala, Y. Kubota, B. Lang, R. Poling, & A. Smith

Nanjing Univ. (China)-
T. Y. Chen, D. Gao, S. Du, M. Qi, B. P. Zhang, Z. Xi Zhang, J. W. Zhao

Ohio State University-
K. Honscheid, & H. Kagan

Univ. of Pennsylvania
W. Selove

Univ. of Puerto Rico
A. Lopez, & W. Xiong

Univ. of Science & Tech. of China - G. Datao, L. Hao, Ge Jin, T. Yang, & X. Q. Yu

Shandong Univ. (China)-
C. F. Feng, Yu Fu, Mao He, J. Y. Li, L. Xue, N. Zhang, & X. Y. Zhang

Southern Methodist Univ - T. Coan, M. Hosack

SUNY Albany - M. Alam

Syracuse University
M. Artuso, S. Blusk, J. Butt, C. Boulahouache, O. Dorjkhaidav J. Haynes, N. Menaa, R. Mountain, N.Nandakumar, L. Redjimi, R. Sia, T. Skwarnicki, S. Stone, J. C. Wang, K. Zhang

Univ. of Tennessee -
T. Handler, R. Mitchell

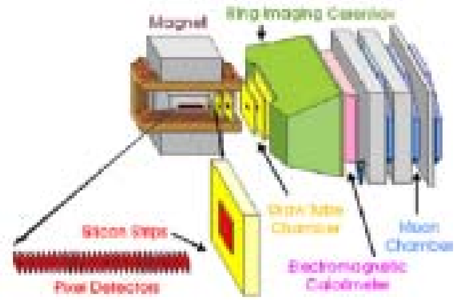
Vanderbilt University -
W. Johns, P. Sheldon, E. Vaandering, & M. Webster

Univ. of Virginia: M. Arenton, S. Conetti, B. Cox, A. Ledovskoy, H. Powell, M. Ronquest, D. Smith, B. Stephens, Z. Zhe

Wayne State University
G. Bonvicini, D. Cinabro, A. Shreiner

University of Wisconsin
M. Sheaff

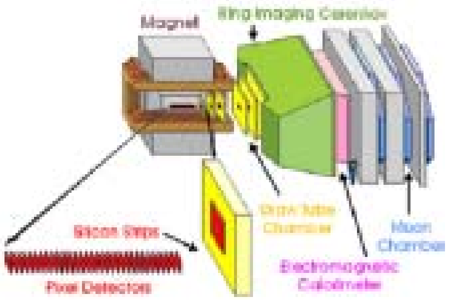
York University - S. Menary



Some Significant Events in B Physics

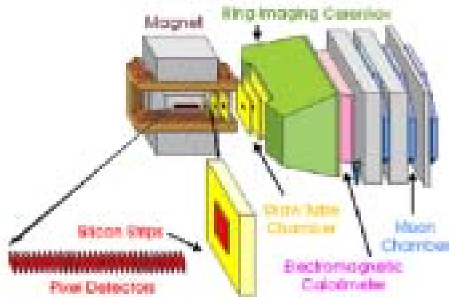
Year	Item	Theory Prediction	~Value	# B's
1983	τ_b	Too small to be observed ~ < 0.1ps	1 ps	$2x10^4$
1987	B^o-$\bar{B}^o$ mixing	Too small to see (~ < 1%) as m_{top} is believed to be ~30 GeV	20%	$2x10^5$
1987	V_{ub}/V_{cb}	No direct prediction	0.1	$2x10^5$
1994	$b\rightarrow s\gamma$	(2.8 ± 0.8) $x10^{-4}$	$2.3x10^{-4}$	$4x10^6$
2001	$\sin(2\beta)$	No direct prediction, but consistent with other measurements	3/4	10^7

- B physics is an experimentally driven field with exciting discoveries, many not predicted.
- As we will see, there is much much more physics to do.



Physics Goals

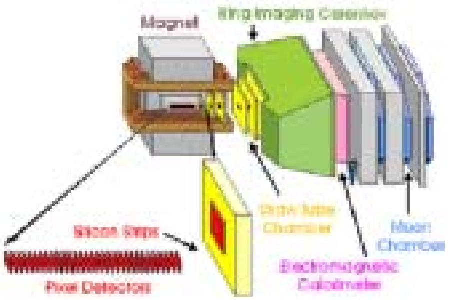
- Discover, or help interpret, New Physics found elsewhere, using b & c decays
- Measure Standard Model parameters, the "fundamental constants"



The Physics

- There is New Physics out there: Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
- BTeV will Investigate:
  - Major Branches
    - *New Physics* via ~~CP~~ phases
    - *New Physics* via Rare Decays
    - Precision determination of CKM Elements (small model dependence)
  - Other Branches (some)
    - Weak decay processes, *B*'s, polarization, Dalitz plots, QCD…
    - Semileptonic decays including Λ_b
    - b & c quark Production
    - Structure: B baryon states
    - B_c decays

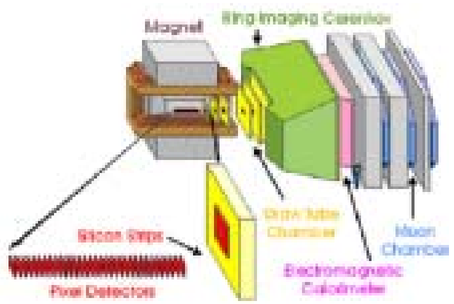
>100 thesis topics



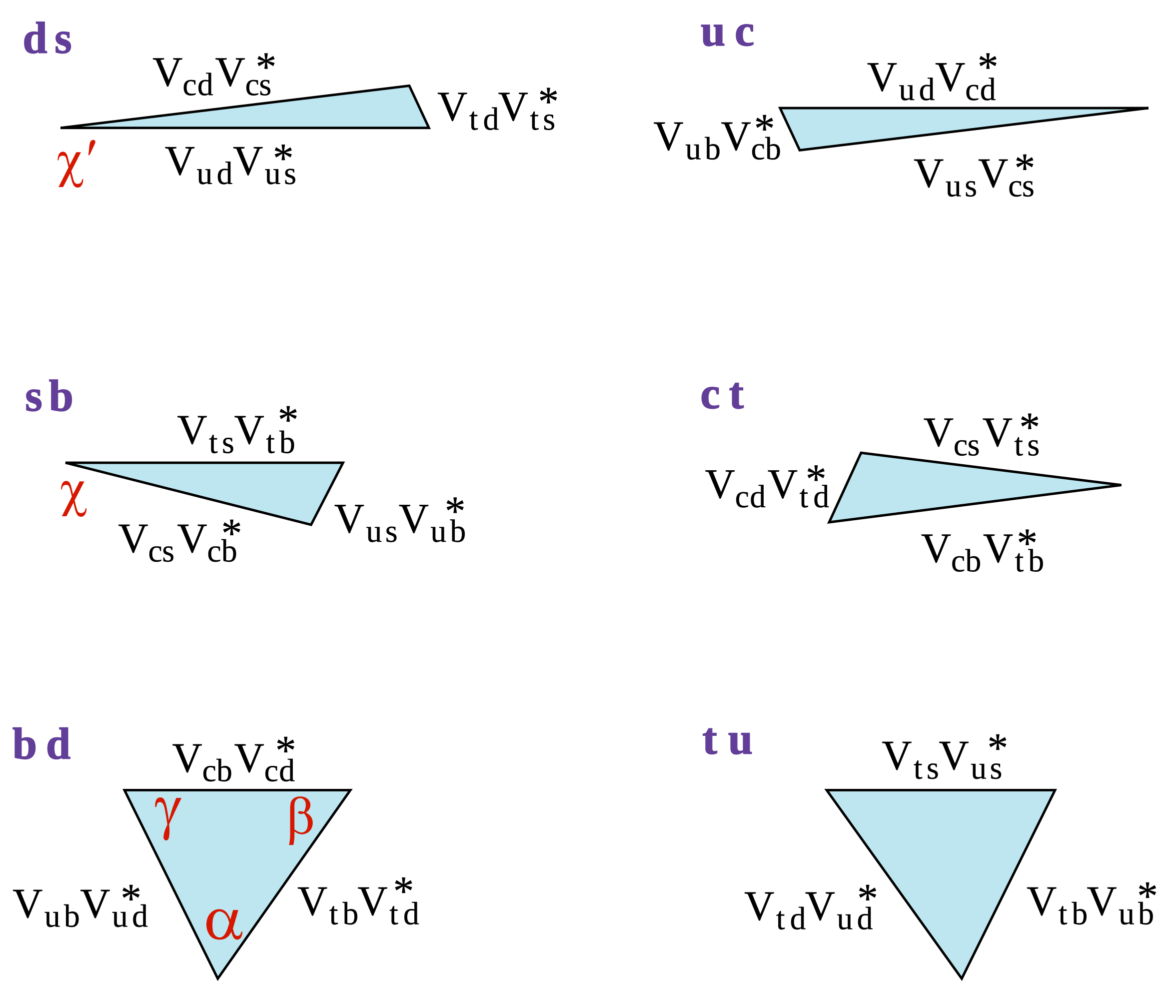
The Basics: Quark Mixing & the CKM Matrix

$$V=\begin{array}{c c}
 & \begin{array}{ccc} d & s & b \end{array} \\
\begin{array}{c} u \\ c \\ t \end{array} & \begin{pmatrix}
1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3\left(\rho-i\eta\left(1-\frac{1}{2}\lambda^2\right)\right) \\
-\lambda & 1-\frac{1}{2}\lambda^2-i\eta A^2\lambda^4 & A\lambda^2\left(1+i\eta\lambda^2\right) \\
A\lambda^3\left(1-\rho-i\eta\right) & -A\lambda^2 & 1
\end{pmatrix}
\end{array}$$

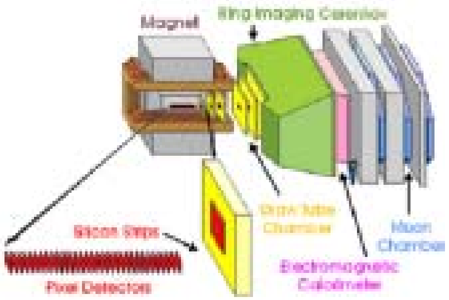
- A, λ, ρ and η are in the Standard Model fundamental constants of nature like G, or α_{EM}
- η multiplies i and is responsible for CP violation
- We know $\lambda=0.22$, $A\sim0.8$; constraints on ρ & η



The 6 CKM Triangles



- From Unitarity
- "ds" - indicates rows or columns used
- There are 4 independent phases: β, γ, χ, χ' (α can be substituted for γ or β)



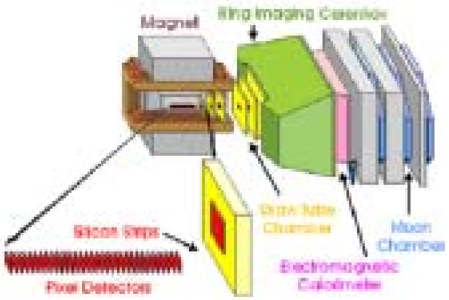
All of The CKM Phases

- The CKM matrix can be expressed in terms of 4 phases, rather than, for example λ, A, ρ, η:

$$\beta = \arg\left(-\frac{V_{tb}V_{td}^{*}}{V_{cb}V_{cd}^{*}}\right) \qquad \gamma = \arg\left(-\frac{V_{ub}^{*}V_{ud}}{V_{cb}^{*}V_{cd}}\right)$$

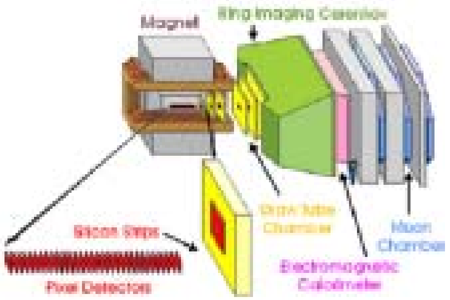
$$\chi = \arg\left(-\frac{V_{cs}^{*}V_{cb}}{V_{ts}^{*}V_{tb}}\right) \qquad \chi' = \arg\left(-\frac{V_{ud}^{*}V_{us}}{V_{cd}^{*}V_{cs}}\right)$$

- $\alpha = \pi - (\beta + \gamma)$, not independent
- α, β & γ probably large, χ small ~2^{o}, χ′ smaller



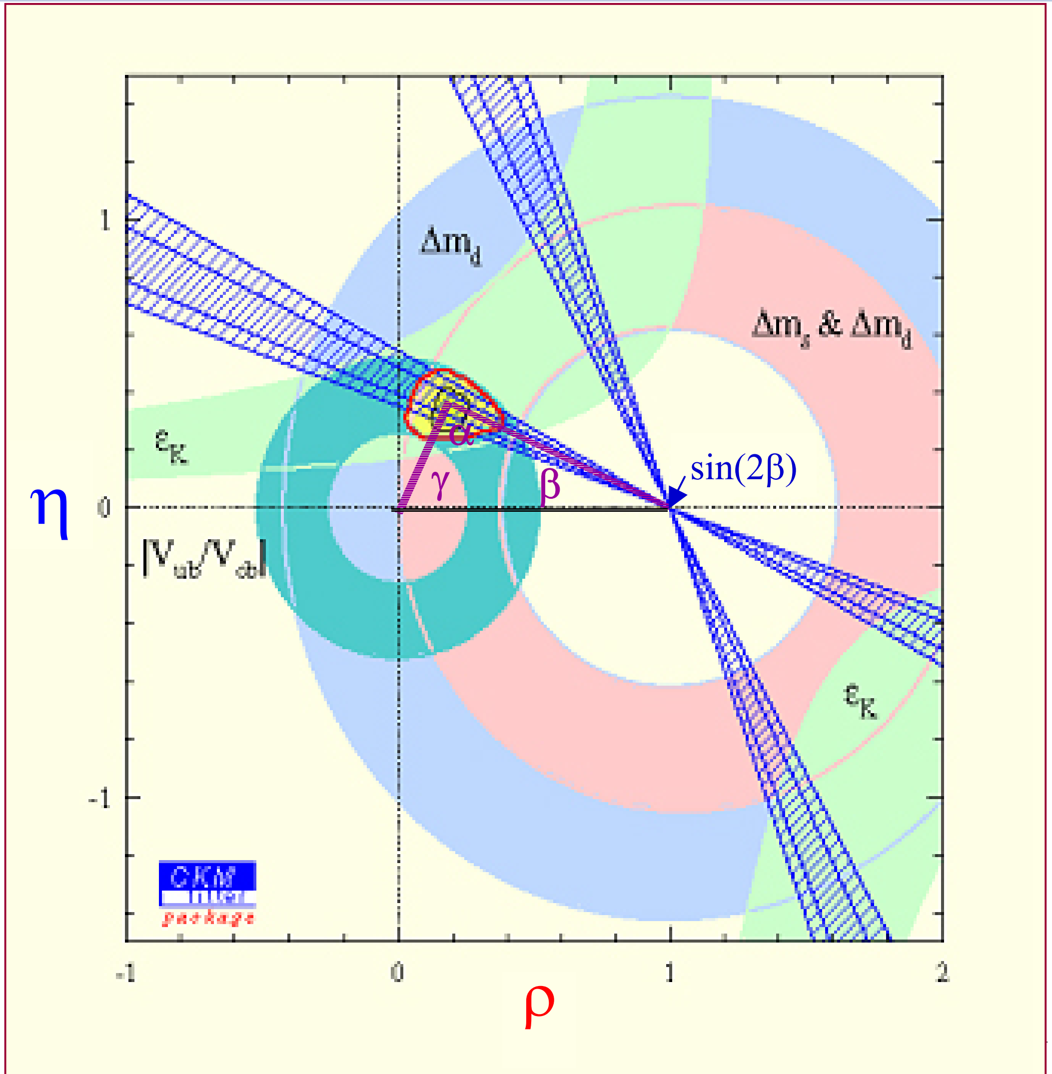
New Physics Tests

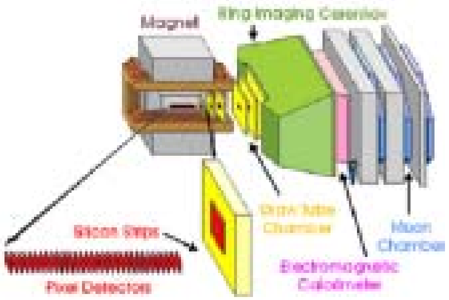
- We can use these CP violating or CP related variables to perform tests for New Physics, or to figure out what is the source of the new physics.
- There are also important methods using Rare Decays, described later
- These tests can be either generic, where we test for inconsistencies in SM predictions independent of specific non-standard model, or model specific
- We will first look at what is already known



Current Status

- Constraints on ρ & η from Nir using Hocker et al.
- Theory parameters are allowed to have equal probability within a restricted but arbitrary range
- Therefore large model dependence for V_{ub}/V_{cb}, ε_K and Δm_d, smaller but significant for Δm_s and virtually none for sin(2β)

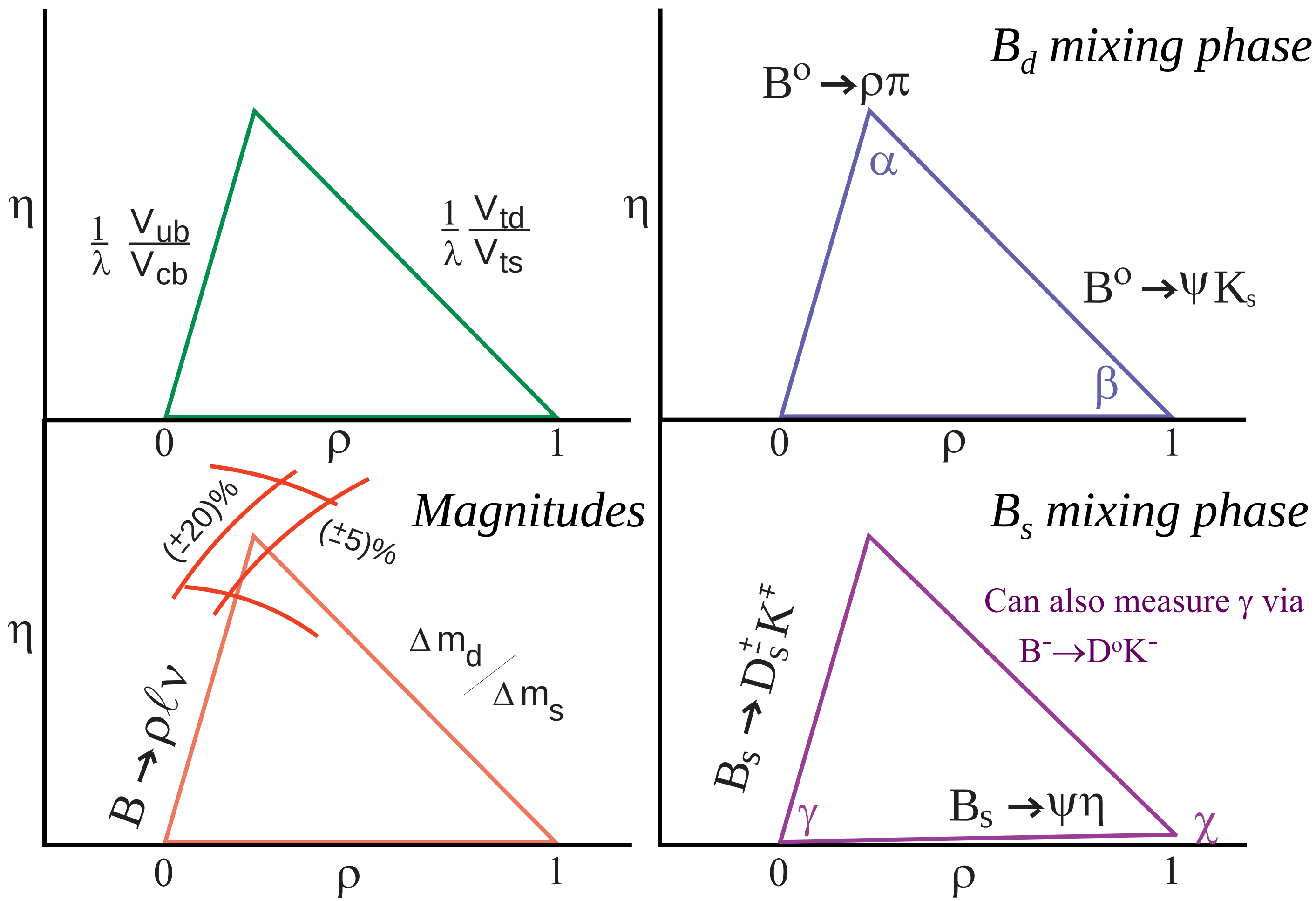


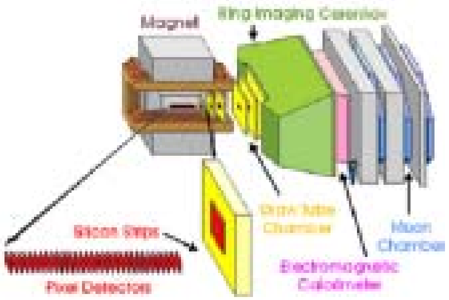


Generic test: Separate Checks

- Use different sets of measurements to define apex of triangle

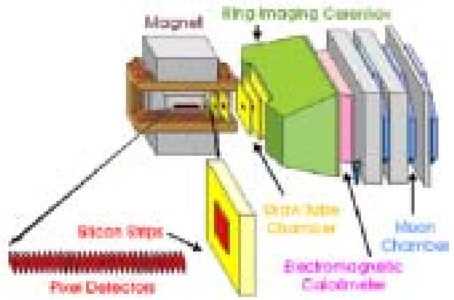
  (ala' Peskin)
- Also have ε_K (CP in K_L ~~system~~)





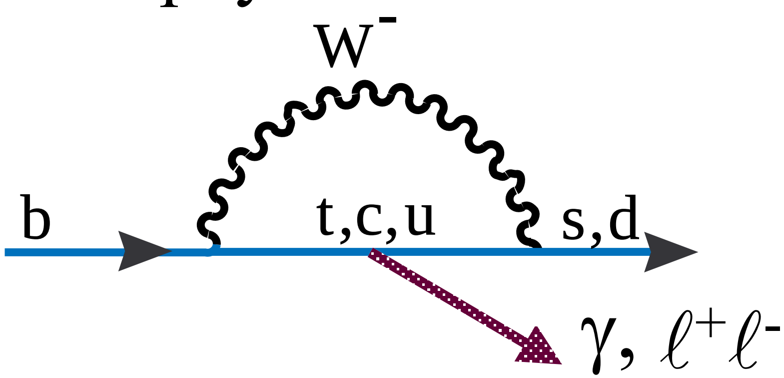
Generic Test: Critical Check using χ

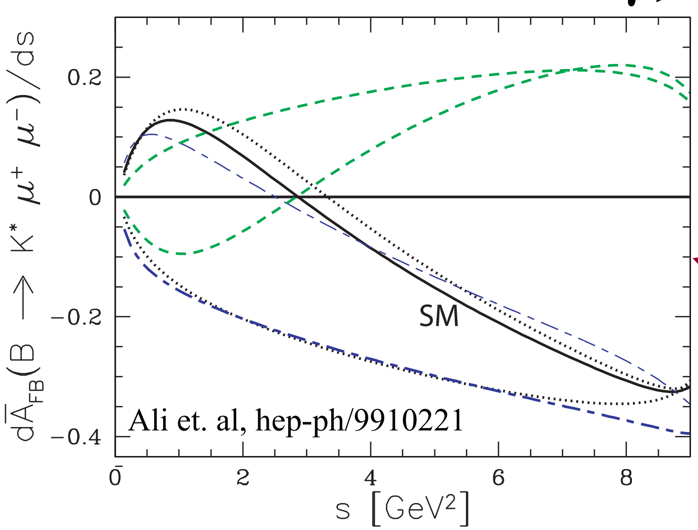
- Silva & Wolfenstein (hep-ph/9610208), (Aleksan, Kayser & London), propose a test of the SM, that can reveal new physics; it relies on measuring the angle χ.
  - BTeV can use CP eigenstates to measure χ, for example $B_s \to J/\psi\eta^{(\prime)}$, $\eta \to \gamma\gamma$, $\eta' \to \rho\gamma$
  - Can also use $J/\psi\phi$, but need complicated angular analysis
  - The critical check is: $$\sin\chi = \lambda^2 \frac{\sin\beta \sin\gamma}{\sin(\beta+\gamma)}$$
  - Very sensitive since $\lambda = 0.2205 \pm 0.0018$
  - Since $\chi \sim 2^{o}$, need lots of data



Rare b Decays

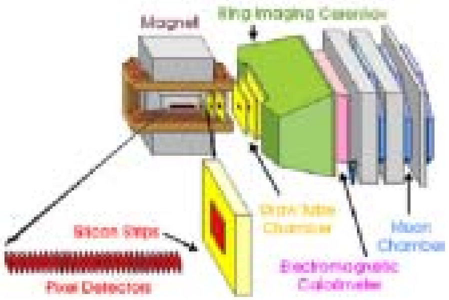
- A good place to find new physics





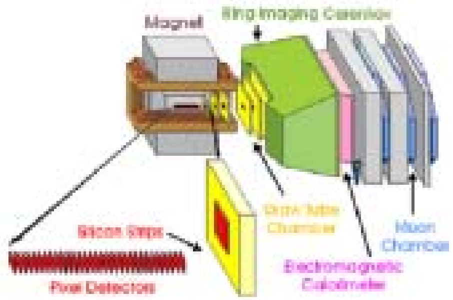
SUSY examples

- New fermion like objects in addition to t, c or u, or new Gauge-like objects
- Inclusive Rare Decays such as inclusive $b \to s\gamma$, $b \to d\gamma$, $b \to s\ell^+\ell^-$
- Exclusive Rare Decays such as $B \to \rho\gamma$, $B \to K^*\ell^+\ell^-$: Dalitz plot & polarization



Tests for New Physics in Rare Decays

- Specific decays, non-specific models (example): $B \rightarrow K\ell^+\ell^-$ & $B \rightarrow K^*\ell^+\ell^-$ effects on dilepton invariant mass & Dalitz plot. "*Especially the decay into K* yields a wealth of new information on the form of the new interactions since the Dalitz plot is sensitive to subtle interference effects*" (Greub, Ioannissian & Wyler hep-ph/9408382)
- Model Specific (example): "Precise measurements of the dilepton invariant mass distributions in the decays $B \rightarrow (s, K^*, K)\ell^+\ell^-$, in particular in the lower dilepton mass region, and the forward-backward asymmetry in the decays $B \rightarrow (s, K^*)\ell^+\ell^-$ will greatly help in discriminating among the SM and various supersymmetric theories." (Ali, Lunghi, Greub & Hiller, hep-ph/0112300)



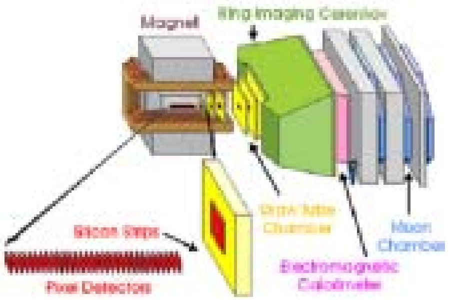
Tests in Specific Models: First Supersymmetry

- Supersymmetry: In general 80 constants & 43 phases
- MSSM: 2 phases (Nir, hep-ph/9911321)
- NP in B^o mixing: θ_D , B^o decay: θ_A, D^o mixing: $\phi_{K\pi}$

Process	Quantity	SM	New Physics
$B^o \to J/\psi K_s$	CP asym	$\sin(2\beta)$	$\sin2(\beta+\theta_D)$
$B^o \to \phi K_s$	CP asym	$\sin(2\beta)$	$\sin2(\beta+\theta_D+\theta_A)$
$D^o \to K^- \pi^+$	CP asym	0	$\sim\sin(\phi_{K\pi})$

Difference $\Rightarrow$ NP

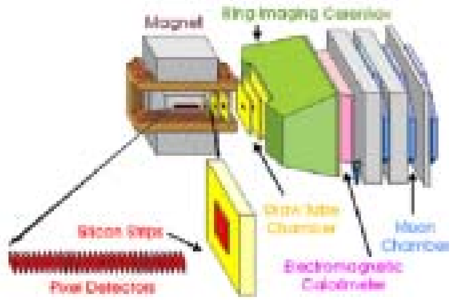
NP



Some SUSY Predictions (Nir)

Model	$d_N/10^{-25}$ neutron	θ_D	θ_A	$asy_{D\to K\pi}$
SM	$\lesssim 10^{-6}$	0	0	0
Approx. Universality	$\gtrsim 10^{-2}$	$\mathcal{O}(0.2)$	$\mathcal{O}(1)$	0
Alignment	$\gtrsim 10^{-3}$	$\mathcal{O}(0.2)$	$\mathcal{O}(1)$	$\mathcal{O}(1)$
Heavy squarks	$\sim 10^{-1}$	$\mathcal{O}(1)$	$\mathcal{O}(1)$	$\mathcal{O}(10^{-2})$
~~Approx. CP~~	$\cancel{\sim 10^{-1}}$	$\cancel{-\beta}$	$\cancel{0}$	$\cancel{\mathcal{O}(10^{-3})}$

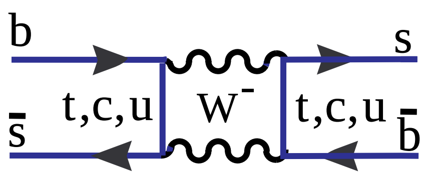
- Note specific pattern in each model $\Rightarrow$ ways of distinguishing among models

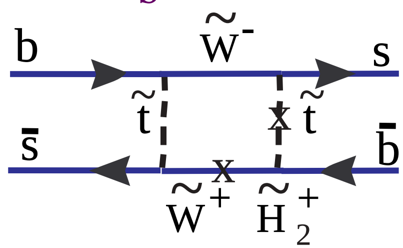


MSSM Measurements from Hinchcliff & Kersting

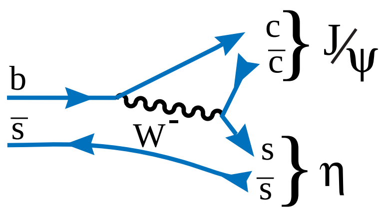
(hep-ph/0003090)

- Contributions to B_s mixing





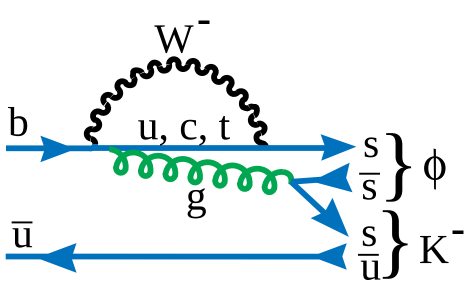
$B_s \rightarrow J/\psi\eta$

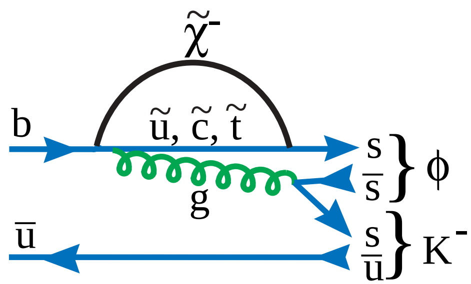


CP asymmetry $\approx 0.1\sin\phi_\mu\cos\phi_A\sin(\Delta m_s t)$, ~10 x SM

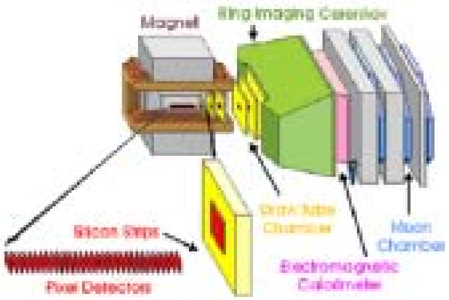
- Contributions to direct CP violating decay

$B^- \rightarrow \phi K^-$



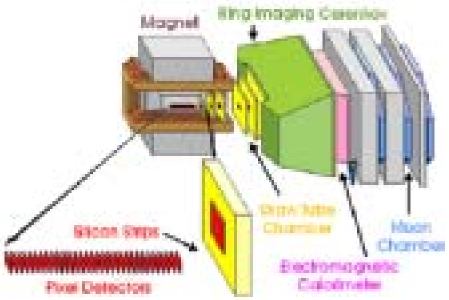


$\text{Asym} = (M_W/m_{squark})^2\sin(\phi_\mu)$, ~0 in SM



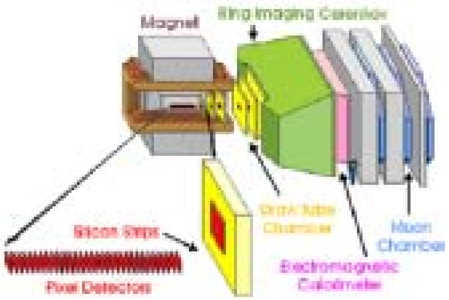
Extra Dimensions

- Chakraverty, Huitu & Kundu, "Effects of Universal Extra Dimensions on B^o Mixing (hep-ph/0212047)
- Kubo & Terao, "Suppressing FCNC and CP-Violating Phases with Extra Dimensions" (hep-ph/0211180)
- Huber, "Flavor Physics and Warped Extra Dimensions" (hep-ph/0211056)
- Barenboim, Botella, & Vives, "Constraining models with vector-like fermions from FCNC in K and B physics" {CPV in $J/\psi K_s$ & $\mathcal{B}(b\rightarrow s\ell^+\ell^-)$} (hep-ph/0105306)
- Aranda & Lorenzo Diaz-Cruz, "Flavor Symmetries in Extra Dimensions" (hep-ph/0207059)
- Chang, Keung & Mohapatra, "Models for Geometric CP Violation with Extra Dimensions" (hep-ph/0105177)
- Agashe, Deshpande & Wu, "Universal Extra Dimensions & $b\rightarrow s\gamma$"(hep-ph/0105084)
- Branco, Gouvea & Rebelo, "Split Fermions in Extra Dimensions & CPV" (hep-ph/0012289)
- Papavassiliou & Santamaria, "Extra Dimensions at the one loop level: $Z\rightarrow bb$ and B-B mixing" (hep-ph/0008151)

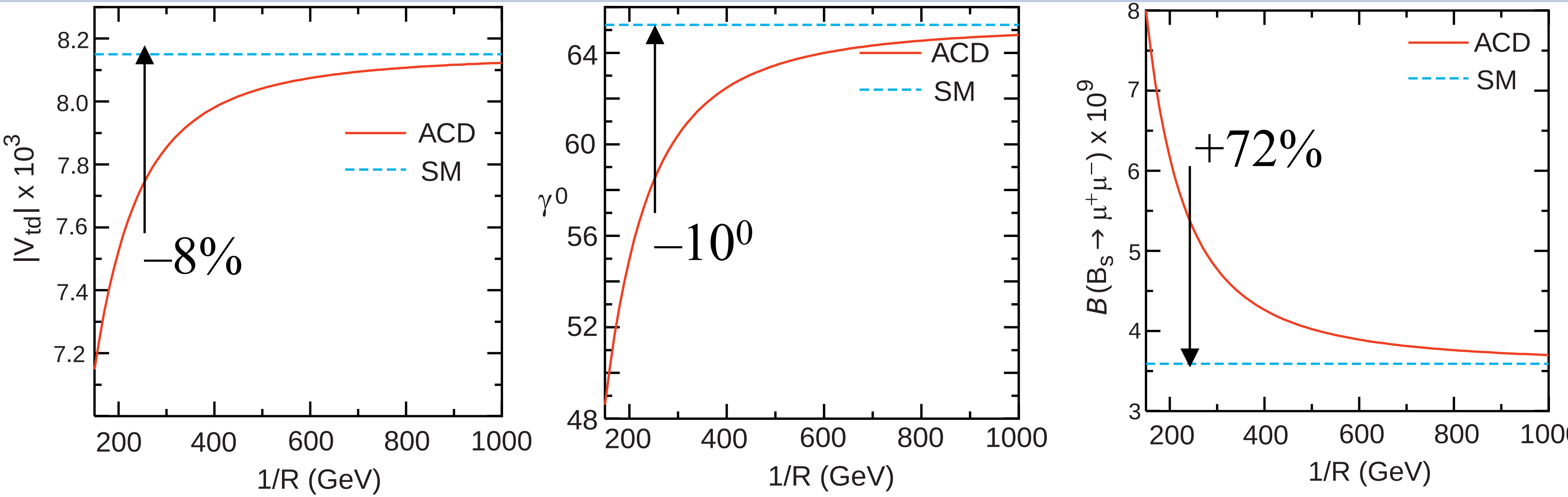


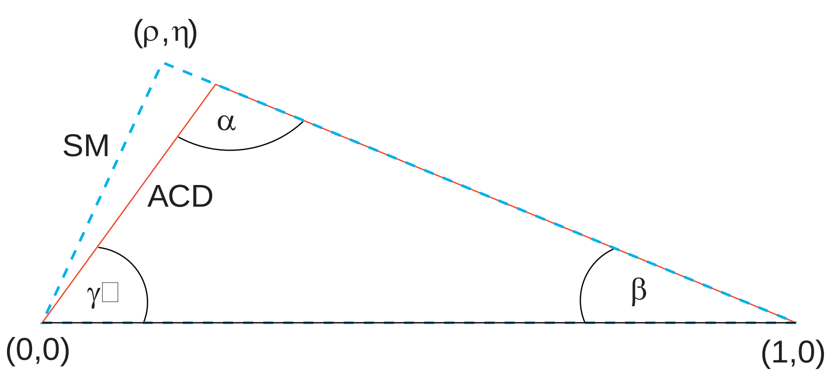
Extra Dimensions – only one

- Extra spatial dimension is compactified at scale $1/R = 250$ GeV on up
- Contributions from Kaluza-Klein modes- Buras, Sprnger & Weiler (hep-ph/0212143) using model of Appelquist, Cheng and Dobrescu (ACD)
- No effect on $|V_{ub}/V_{cb}|$, $\Delta M_d/\Delta M_s$, $\sin(2\beta)$

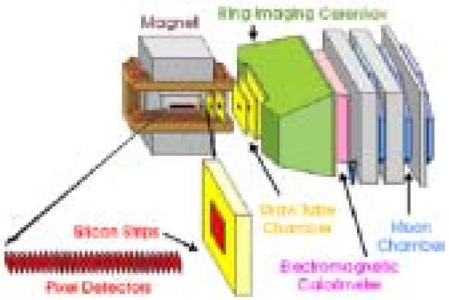


One Extra Dimension





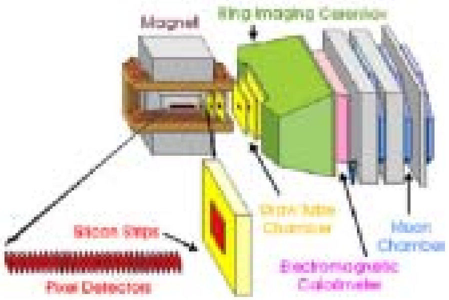
- Precision measurements needed for large 1/R



SO(10)

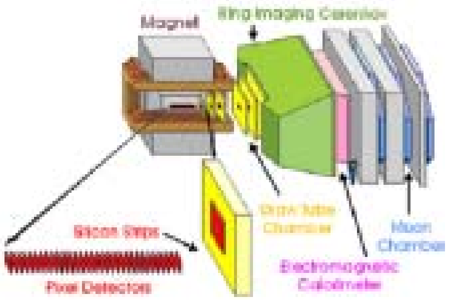
ala' Chang, Masiero & Murayama hep-ph/0205111

- Large mixing between ν_τ and ν_μ (from atmospheric ν oscillations) can lead to large mixing between $\tilde{b}_R$ and $\tilde{s}_R$.
- This does not violate any known measurements
- Leads to large CPV in B_s mixing, deviations from $\sin(2\beta)$ in $B^o \to \phi\, K_s$ and changes in the phase γ



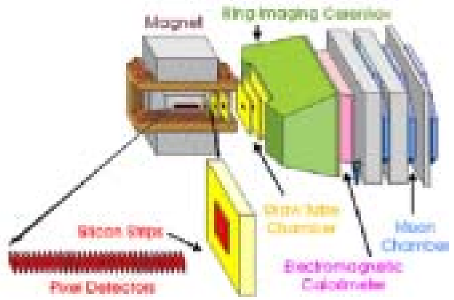
Other Models

- 2 Higgs & Multi-Higgs Doublet Models- *large effects in ε_K, CP in $D^o \rightarrow K^- \pi^+$; few % effects in B^o (Nir); CP violation in $b \rightarrow s\gamma$, 1-10% >> SM (Wolfenstein & Wu)*
- Left-Right Symmetric Model- *"contributions compete with or even dominate over SM contributions to B_d and B_s mixing. This means that $\not{CP}$ asymmetries into CP eigenstates could be substantially different from the SM prediction"* (Nir)
- Extra Down Singlet Quarks- *"dramatic deviations from SM predictions for CP asymmetries in B decays are not unlikely" (Nir)*



Other Models II

- FCNC Couplings of the Z boson-
  - *"Both the sign and magnitude of the decay leptons in $B \to K^* \ell^+ \ell^-$, carry sensitive information on new physics. Potential effects are on the order of 10%, compared to a entirely negligible SM asymmetry of ~10^{-3}"* (Buchalla, Hiller & Isidori hep-ph/0006163)
  - "These models can explain a low values of sin(2β); furthermore they predict x20 enhancement of $b \to d \ell^+ \ell^-$ ($B \to \pi \ell^+ \ell^-$)" (Barenboim, Botella & Vives hep-ph/0012197)
- Noncommutative Geometry- *"If the geometry of space-time is noncommutative i.e. $[x_\mu, x_\nu] = i\theta_{\mu\upsilon}$, then CP violating effects may be manifest at low energy. For a scale ≤ 2 TeV there are comparable effects to the SM"* (Hinchliffe & Kersting hep-ph/0104137)



Other Models III

- 4th Generation- B mixing, (Huo hep-ph/0006110)
- MSSM without new flavor structure-
  - Ali & London (hep-ph/9907243) propose:

$$\Delta M_d = \Delta M_d(\mathrm{SM})\left[1+f\left(m_{\chi_2^\pm}, m_{\tilde{t}_R}, m_{H^\pm}, \tan\beta\right)\right]$$

$$\Delta M_s = \Delta M_s(\mathrm{SM})\left[1+f\left(m_{\chi_2^\pm}, m_{\tilde{t}_R}, m_{H^\pm}, \tan\beta\right)\right]$$

$$|\varepsilon_K| = \frac{G_F^2 f_K^2 M_K M_W^2}{6\sqrt{2}\pi^2 \Delta M_K}\hat{B}_K (A^2\lambda^6\bar{\eta})[y_c\{\hat{\eta}_{ct} f_3(y_c, y_t) - \hat{\eta}_{cc}\}$$

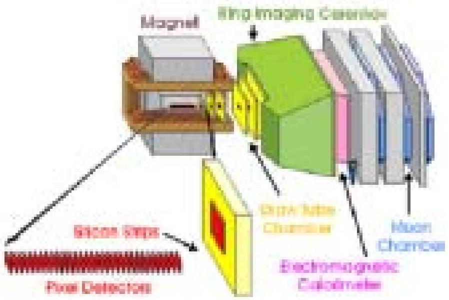
$$+ \hat{\eta}_{tt} y_t f_2(y_t)\left[1+f\left(m_{\chi_2^\pm}, m_{\tilde{t}_R}, m_{H^\pm}, \tan\beta\right)\right] A^2\lambda^4(1-\bar{\rho})]$$

  - *CP violation in $b \to s\gamma$ up to 5%*

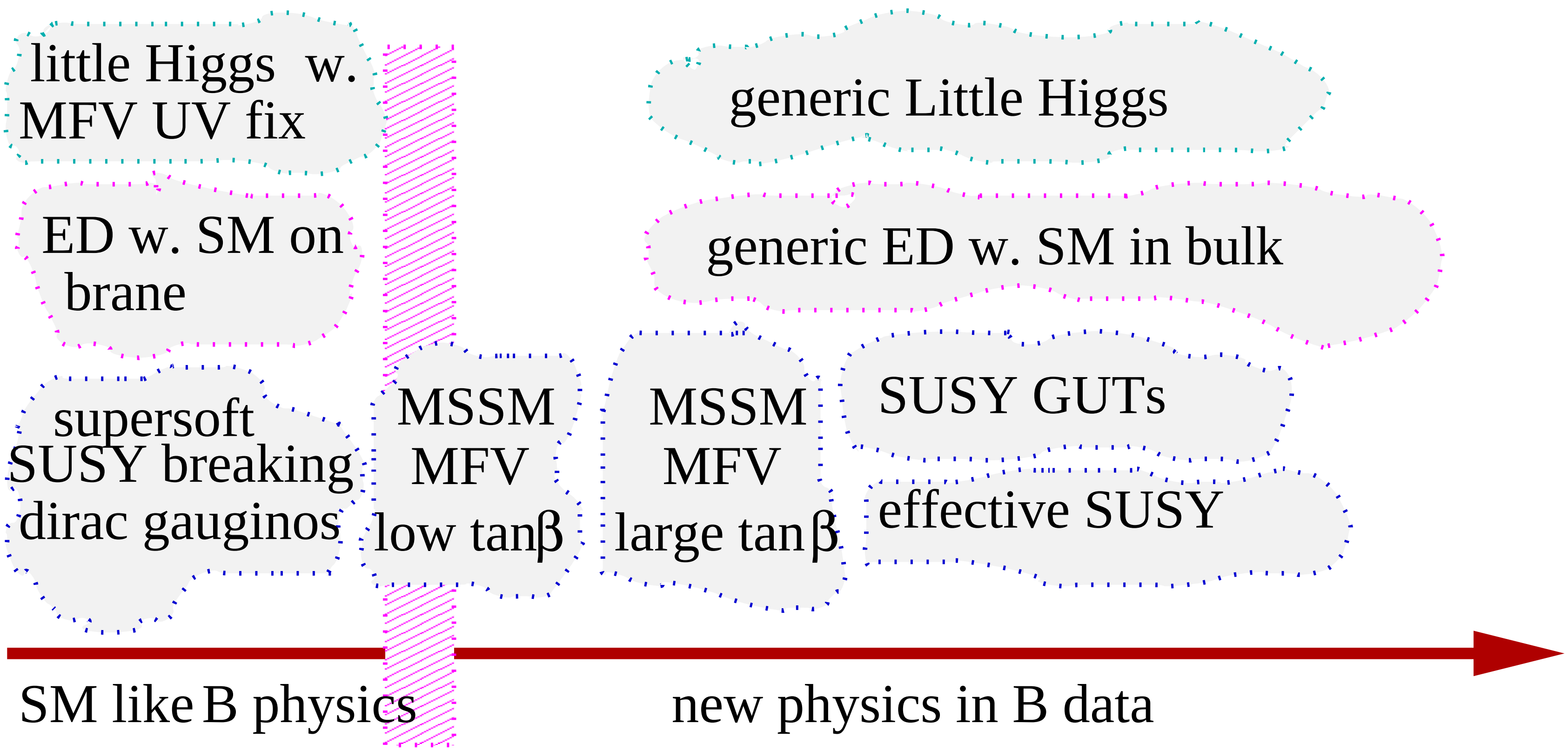
(A. Bartl et. al, hep-ph/0103324)

0.8 > f > 0.2

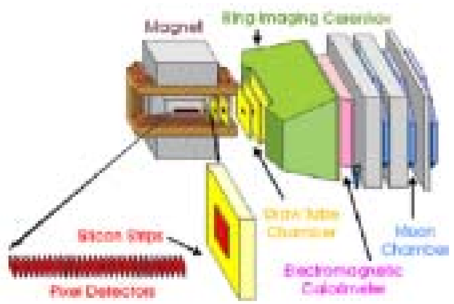
So large effects in B mixing and ε_K. Will reflect in an in-consistency between α, β & γ and CKM determinations of (η,ρ) using mixing, V_{ub}/V_{cb}, and/or ε_K



Possible Size of New Physics Effects



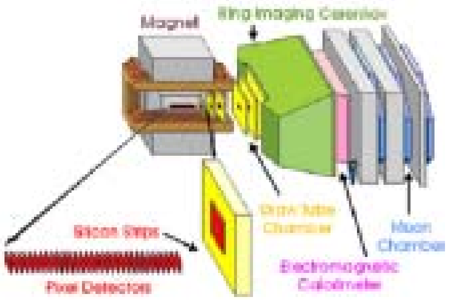
- From Hiller hep-ph/0207121



Summary of New Physics

- We are sensitive using b and c decays in loop diagrams to mass scales ~few TeV depending on couplings (model dependent). The New Physics effects in these loops may be the <u>only</u> way to distinguish among models.
- Masiero & Vives: *"the relevance of SUSY searches in rare processes is not confined to the usually quoted possibility that indirect searches can arrive 'first' in signaling the presence of SUSY. Even after the possible direct observation of SUSY particles, the importance of FCNC & CPV in testing SUSY remains of utmost relevance. They are & will be complementary to the Tevatron & LHC establishing low energy supersymmetry as the response to the electroweak breaking puzzle"* (hep-ph/0104027)

We agree, except we would replace "SUSY" with "New Physics"



Connections

LHC
New Particles

new physics, found 1st in either place; specified in both

> 100 papers giving examples

Rare K Decays

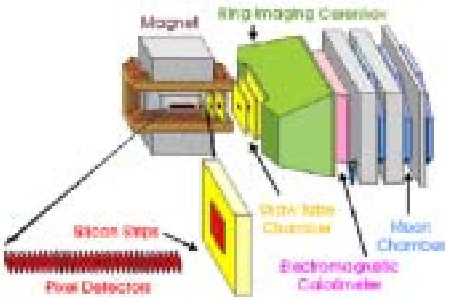
ν
Mixing

new models of GUTS & flavor

SO(10) etc;
Flavor Symmetries in Extra Dimensions

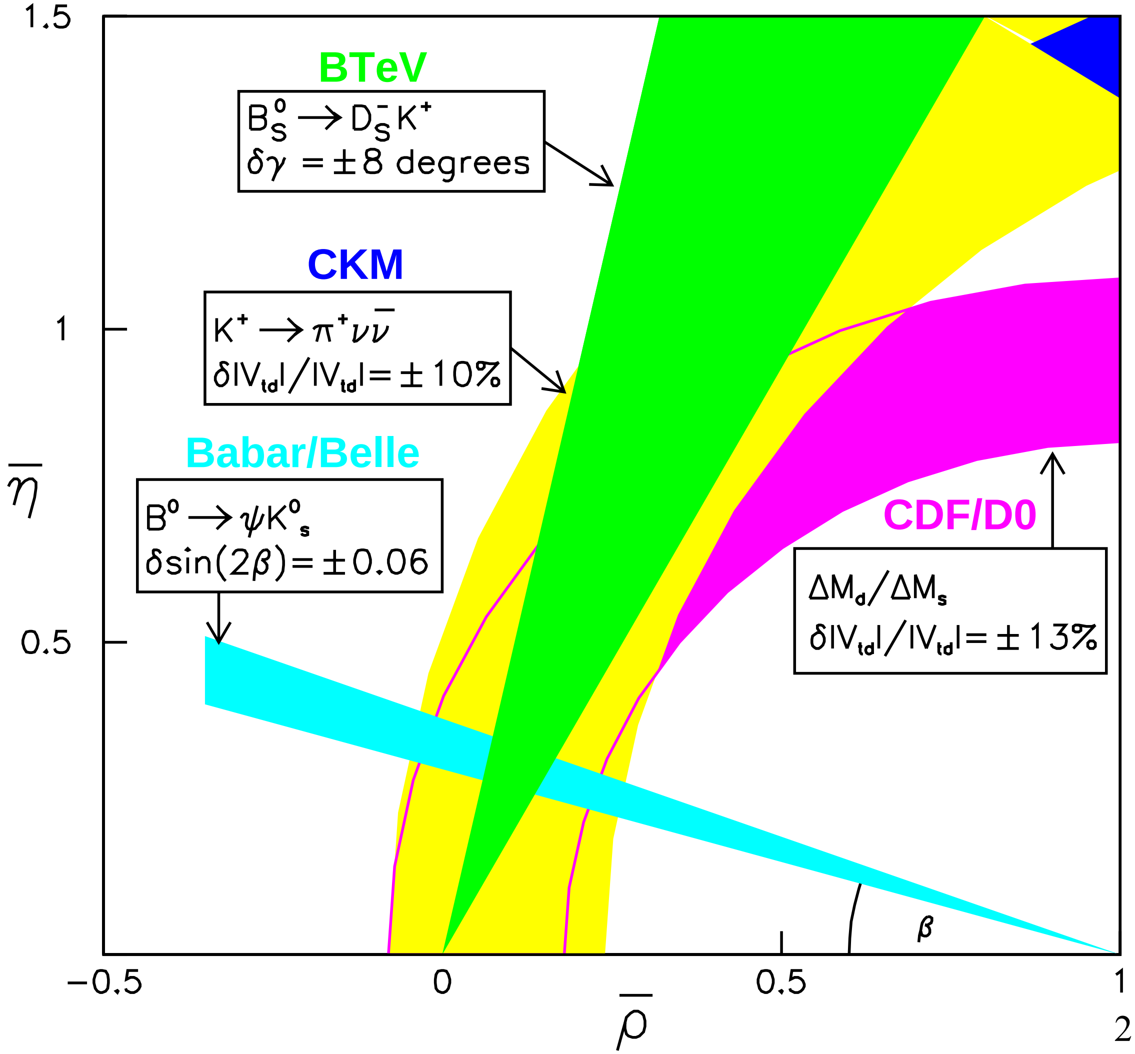
$\not{CP}$ & Rare
b & c decays

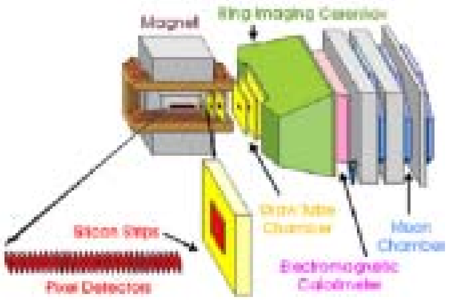
Other
b & c physics



Connection with $K^+ \rightarrow \pi^+ \nu\bar{\nu}$

- Nice check that KM model is flavor independent

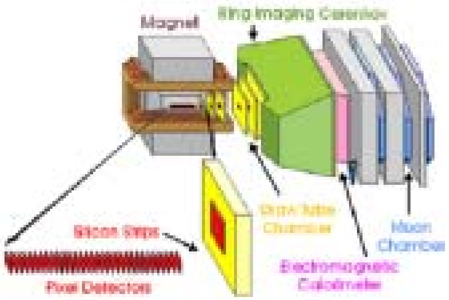




Summary of Required Model Independent Measurements for CKM tests

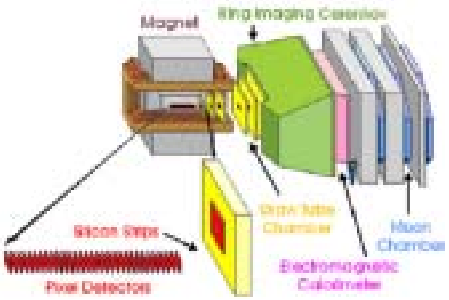
Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^o \to \rho\,\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\cos(2\alpha)$	$B^o \to \rho\,\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\sin(\gamma)$	$B_s \to D_s\,K^-$	✓	✓		✓
$\sin(\gamma)$	$B^o \to D^o\,K^-$	✓	✓		
$\sin(2\chi)$	$B_s \to J/\psi\,\eta',\ J/\psi\,\eta$		✓	✓	✓
$\sin(2\beta)$	$B^o \to J/\psi\,K_s$				
$\cos(2\beta)$	$B^o \to J/\psi\,K^o,\ K^o \to \pi\ell\nu$		✓		
x_s	$B_s \to D_s\,\pi^-$	✓	✓		✓
$\Delta\Gamma$ for B_s	$B_s \to J/\psi\,\eta',\ K^+K^-,\ D_s\,\pi^-$	✓	✓	✓	✓

There are other modes useful for measuring these physics quantities



Why do b & c decay physics at the Fermilab Tevatron?

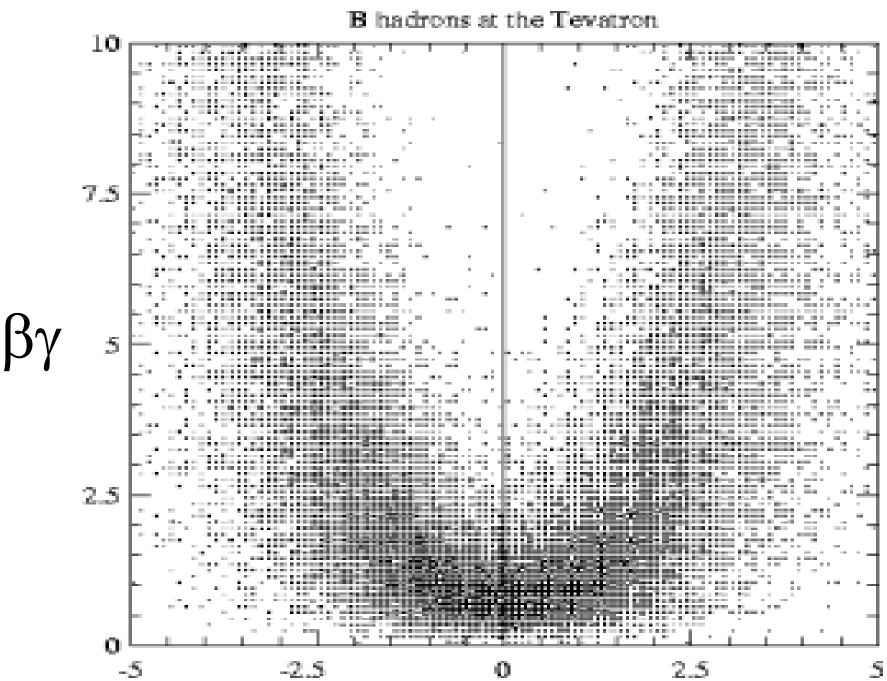
- Large samples of b quarks are available, with the Main Injector, the collider will produce $\sim 4 \times 10^{11}$ b hadrons per 10^7 sec at $L = 2 \times 10^{32}$ cm^{-2}s^{-1}.
- e^+e^- machines operating at the $\Upsilon(4S)$ at L of 10^{34} would produce 2×10^8 B's per 10^7 s.
- B_s & Λ_b and other b-flavored hadrons are accessible for study at the Tevatron.
- Charm rates are ~10x larger than b rates



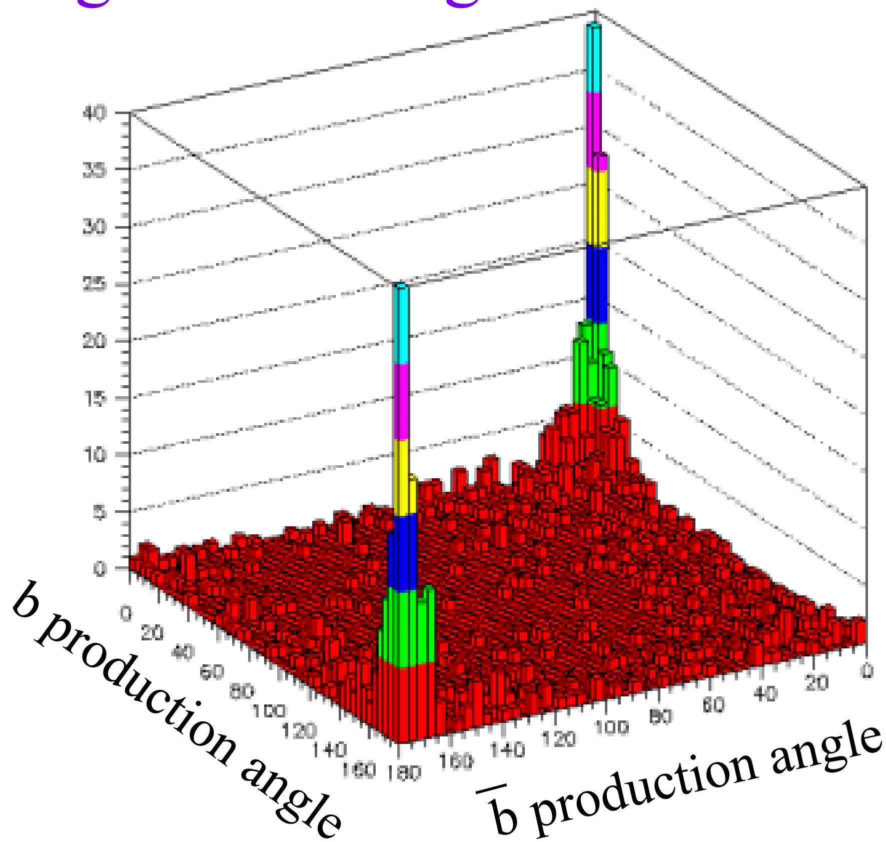
Characteristics of hadronic b production

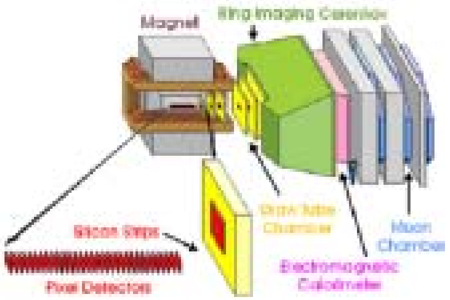
The higher momentum b's are at larger η's

b production peaks at large angles with large $\bar{b}b$ correlation

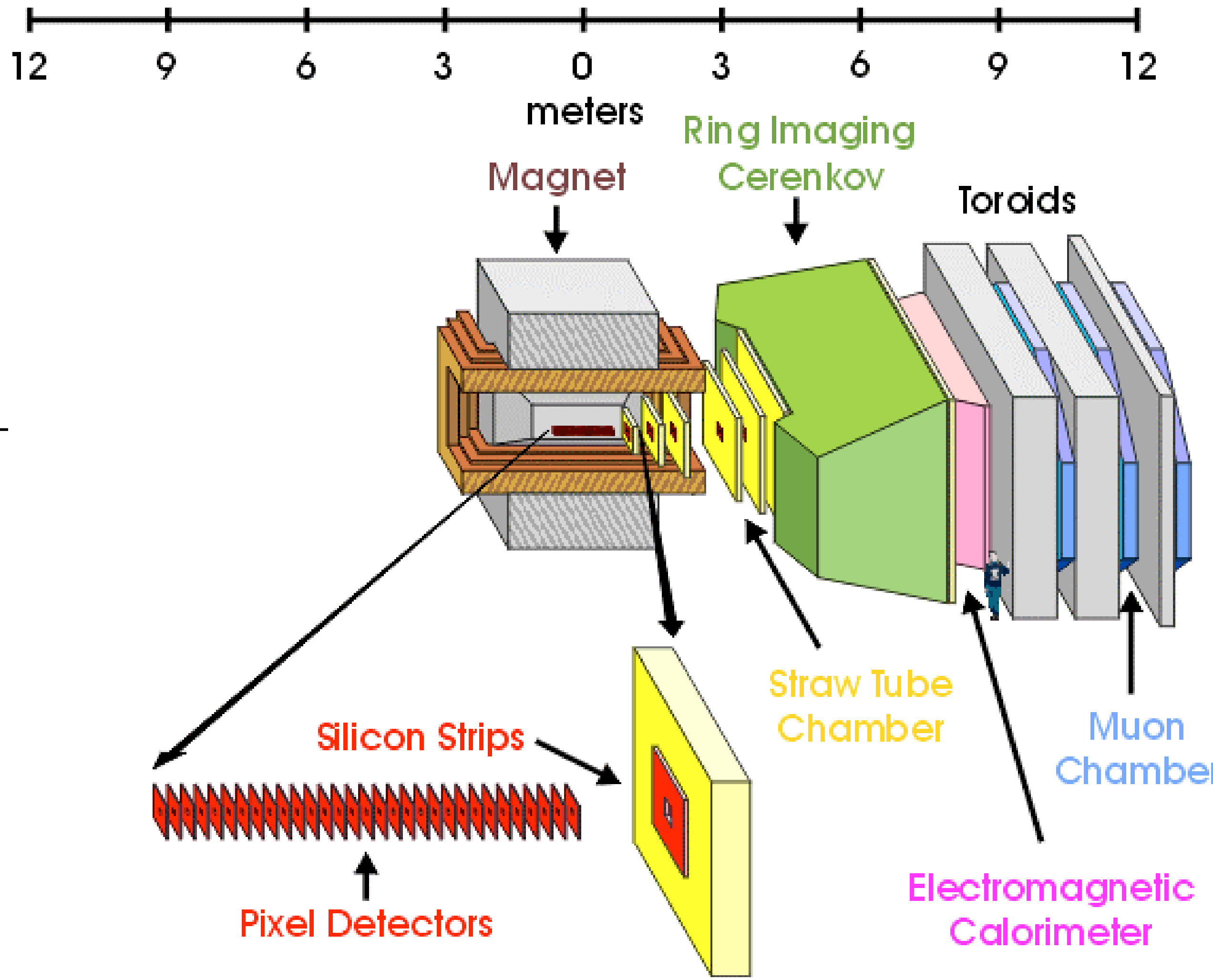


$\eta = -\ln(\tan\frac{\theta}{2})$

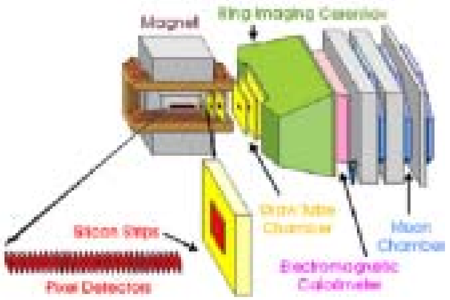




The BTeV Detector



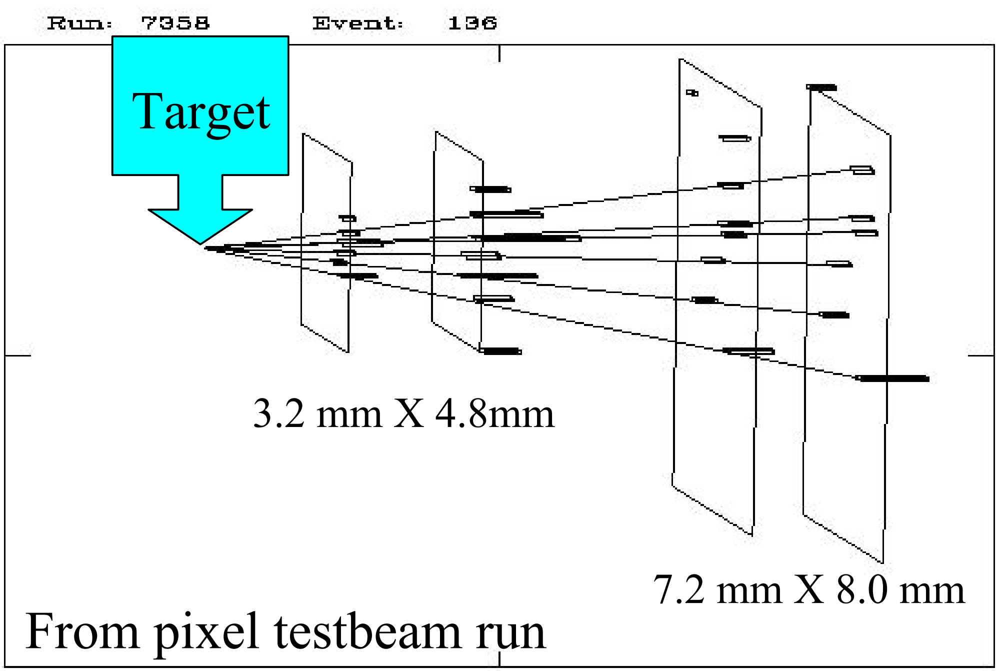
beam line

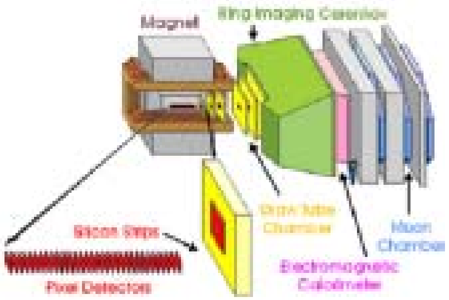


Physics Simulations Tools

Full GEANT has multiple scattering, bremsstrahlung, pair conversions, hadronic interactions and decays in flight; smears hits and refits the tracks using "Kalman Filter." No pattern recognition (except for trigger). However, we do not expect large pattern recognition problems

This track density is 10x higher than what is expected in BTeV!

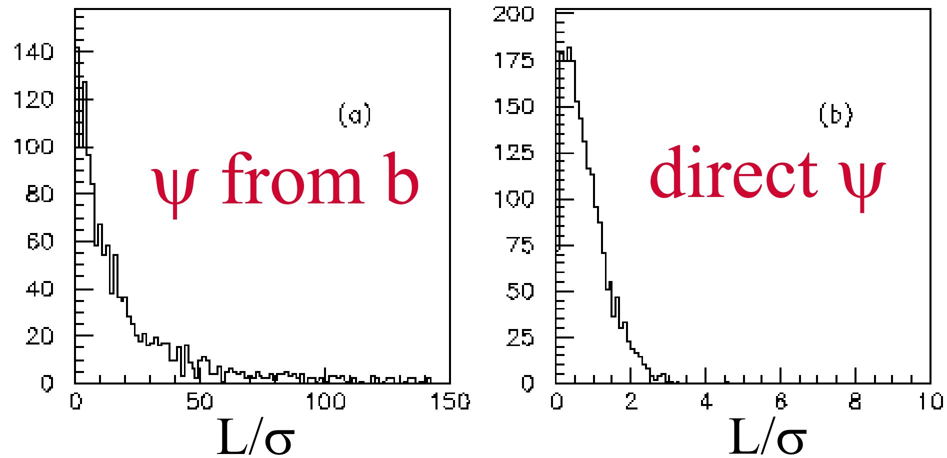


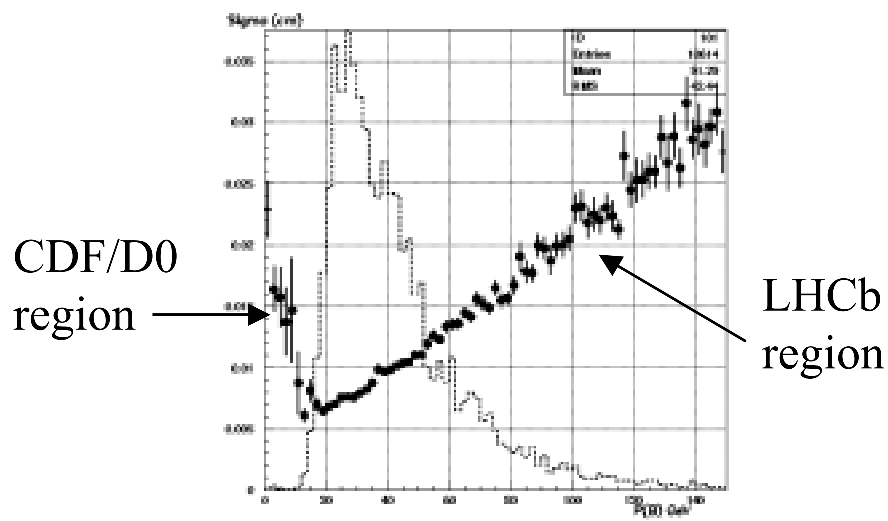


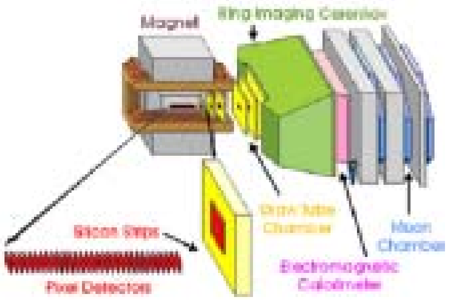
Fundamentals: Decay Time Resolution

- Excellent decay time resolution
  - Reduces background
  - Allows detached vertex trigger
- The average decay distance and the uncertainty in the average decay distance are functions of B momentum:

$$<L> = \gamma\beta c\tau_B$$
$$= 480\ \mu m \times p_B/m_B$$

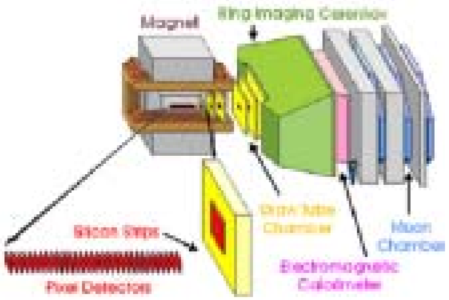






Detached Vertex Trigger

- Level I Trigger uses information from the Pixel Detector to find the primary vertex and then look for tracks that are detached from it
- The simulation does the pattern recognition. It uses hits from GEANT including multiple scattering, bremsstrahlung, pair conversions, hadronic interactions and decays in flight

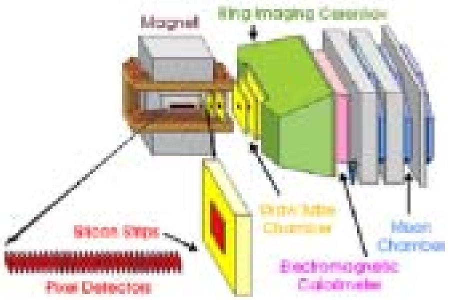


Trigger Performance

- For a requirement of at least 2 tracks detached by more than 6σ, we trigger on only 1% of the beam crossings and achieve the following efficiencies for these states:

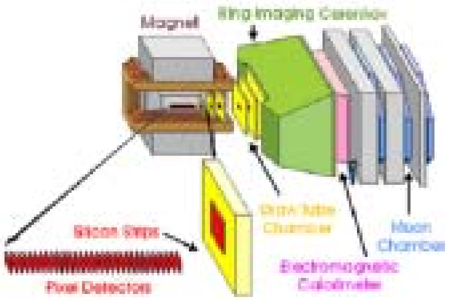
State	efficiency(%)	state	efficiency(%)
$B \rightarrow \pi^+\pi^-$	63	$B^o \rightarrow K^+\pi^-$	63
$B_s \rightarrow D_s K$	74	$B^o \rightarrow J/\psi\ K_s$	50
$B^- \rightarrow D^o K^-$	70	$B_s \rightarrow J/\psi K^*$	68
$B^- \rightarrow K_s \pi^-$	27	$B^o \rightarrow K^* \gamma$	40

$< 2 >$ interactions per crossing



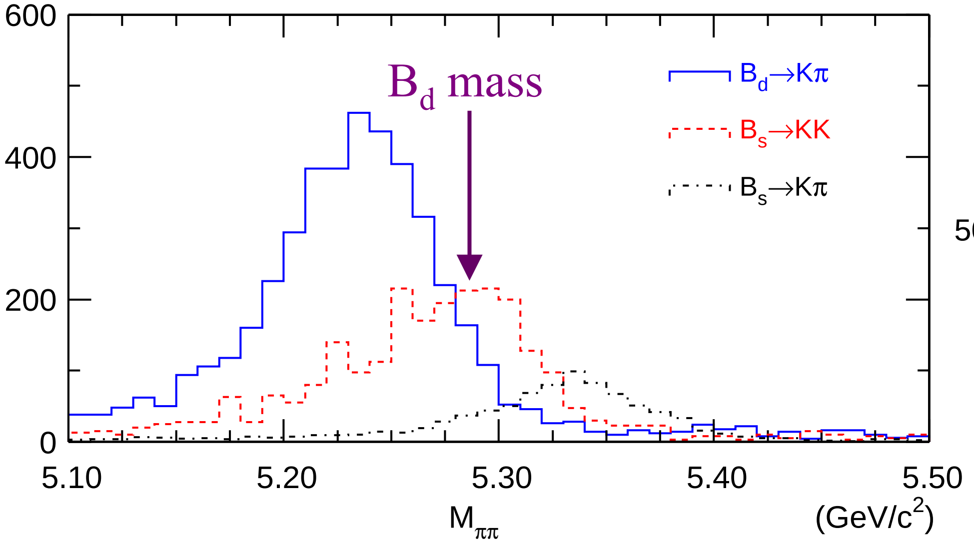
A sample calculation: $B^o \rightarrow \pi^+\pi^-$

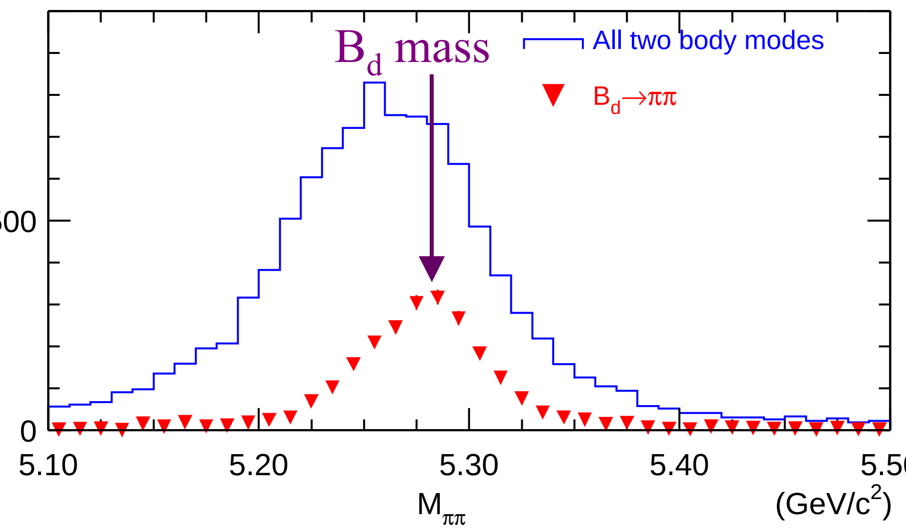
Cross-section	100 μb
Luminosity (<2> interactions/crossing)	2×10^{32}
# of B^o/Year (10^7 s)	1.5×10^{11}
$\mathcal{B}(B^o \rightarrow \pi^+\pi^-)$	0.45×10^{-5}
Reconstruction efficiency	0.04
Particle I.D. efficiency	0.82
Triggering efficiency (after all other cuts) L1+L2	0.55
# ($\pi^+\pi^-$)	12,200
ϵD^2 for flavor tags ($K^\pm$, $\ell^\pm$, same + opposite side jet tags)	0.1
# of tagged $\pi^+\pi^-$	1,220
Signal/Background	3
Error in $\pi^+\pi^-$ asymmetry (including bkgrd)	±0.033

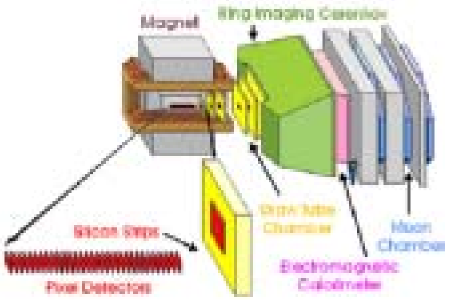


$B^o \rightarrow \pi^+ \pi^-$ Analysis: The Importance of Particle ID

- Require that each π be properly identified in the RICH. Otherwise the measurement is probably impossible.

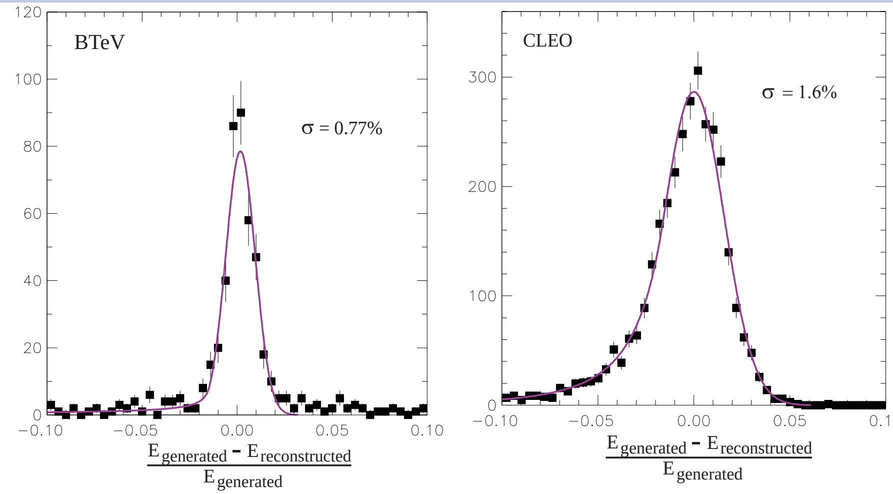


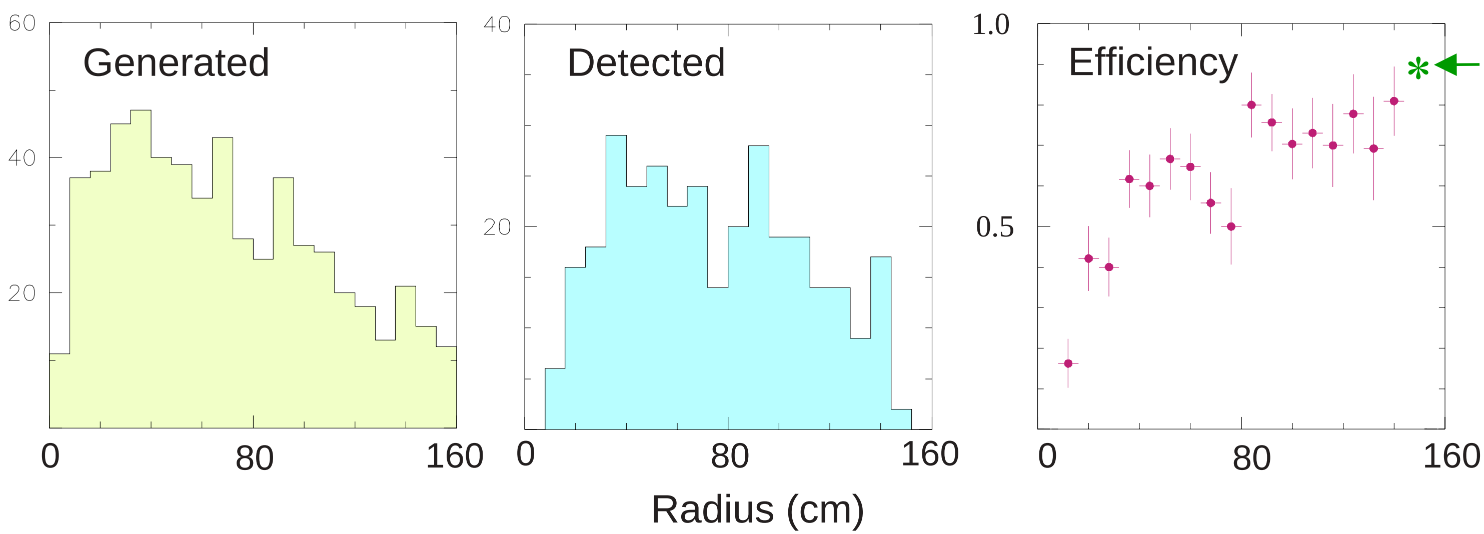




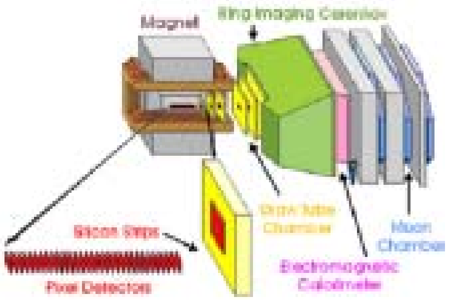
EM calorimetry using $PbWO_4$ Crystals

- GEANT simulation of $B^o \rightarrow K^*\gamma$, for BTeV & CLEO
- Isolation & shower shape cuts on both





CLEO barrel ε=89%



Measuring α Using $B^o \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^o$

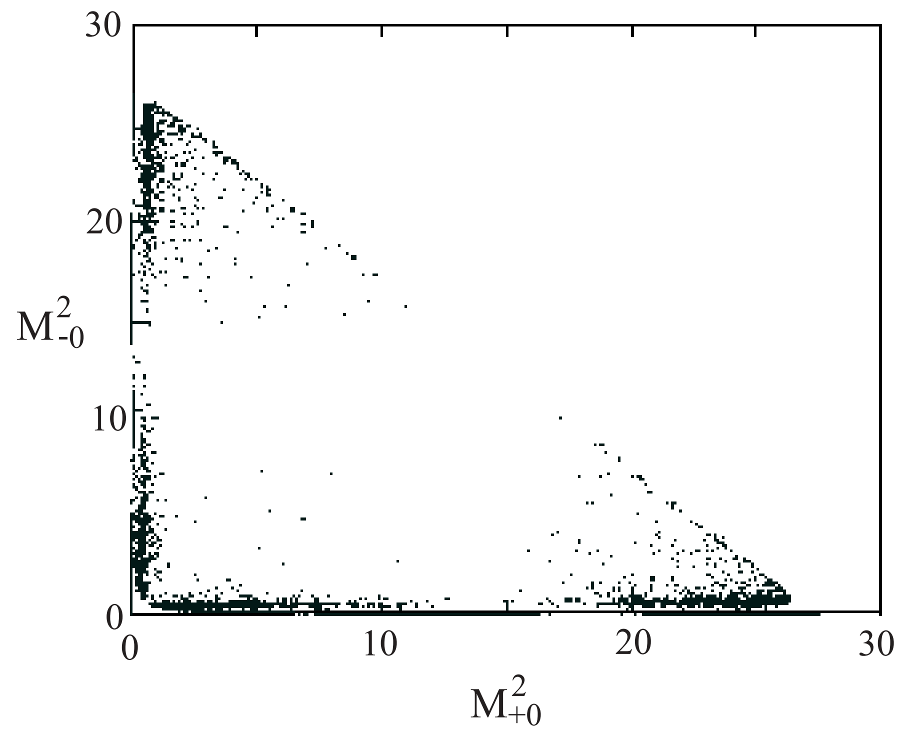
- A Dalitz Plot analysis gives **both** $\sin(2\alpha)$ and $\cos(2\alpha)$ (Snyder & Quinn)
- Measured branching ratios are:

$\mathcal{B}(B^- \rightarrow \rho^o\pi^-) = \sim 10^{-5}$

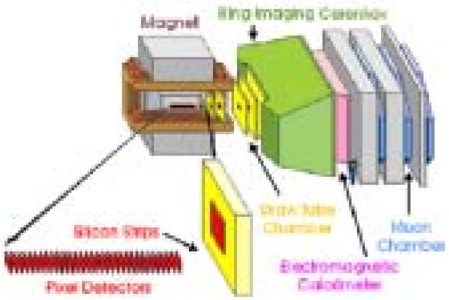
$\mathcal{B}(B^o \rightarrow \rho^-\pi^+ + \rho^+\pi^-)$

$= \sim 3\text{x}10^{-5}$

$\mathcal{B}(B^o \rightarrow \rho^o\pi^o) < 0.5\text{x}10^{-5}$



Snyder & Quinn showed that 1000-2000 tagged events are sufficient

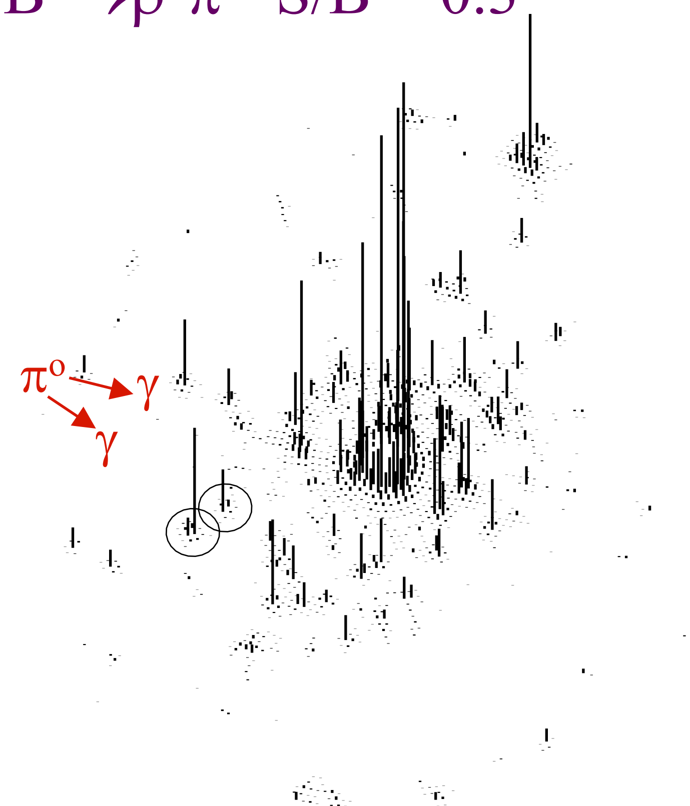


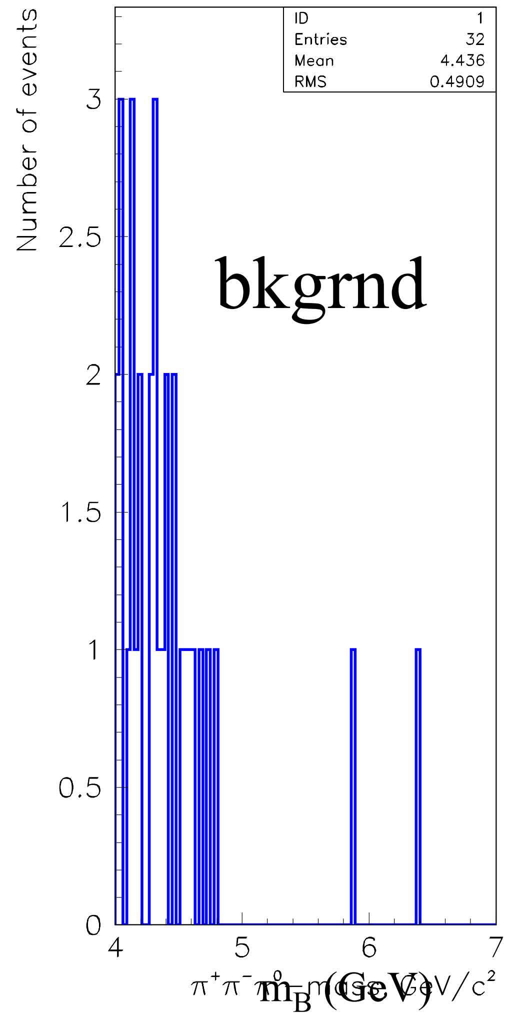
$B^o \to \rho\pi$

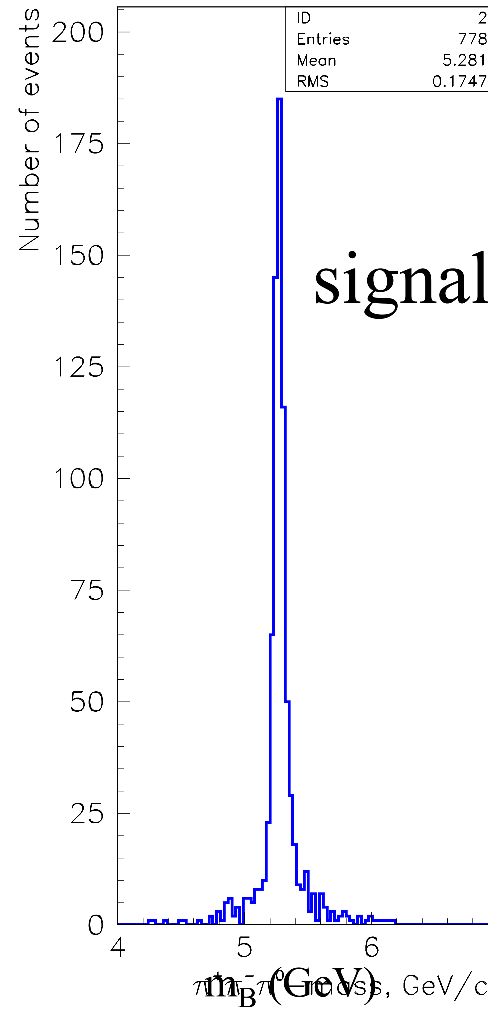
Based 9.9×10^6 bkgrnd events

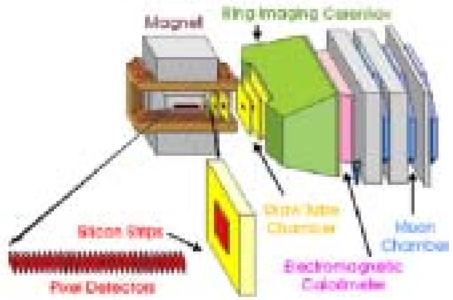
$B^o \to \rho^+\pi^-$ S/B = 4.1

$B^o \to \rho^o\pi^o$ S/B = 0.3



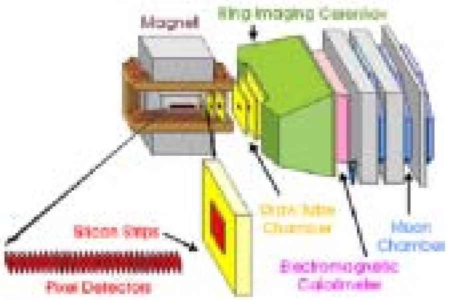






Physics Reach CKM in 10^7 s (Model Independent)

Reaction	$\mathcal{B}$(B) ($\times 10^{-6}$)	# of Events	S/B	Parameter	Error or (Value)
$B_s \to D_s K^-$	300	7500	7	$\gamma - 2\chi$	8^o
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^o \to J/\psi K_S$ $J/\psi \to \ell^+ \ell^-$	445	168,000	10	sin(2β)	0.017
$B^o \to J/\psi K^o$, $K^o \to \pi \ell \nu$	7	250	2.3	cos(2β)	~0.5
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13^o
$B_s \to J/\psi \eta$,	330	2,800	15		
$B_s \to J/\psi \eta'$	670	9,800	30	sin(2χ)	0.024
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	~4^o

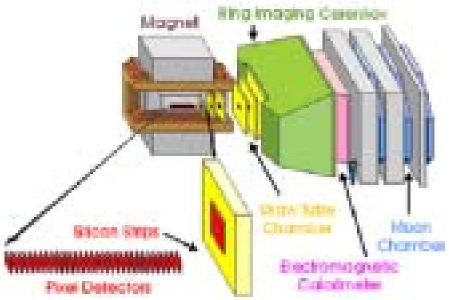


Physics Reach CKM in 10^7 s (Model Dependent)

Model Dependent measures of γ, may be useful for ambiguity resolution

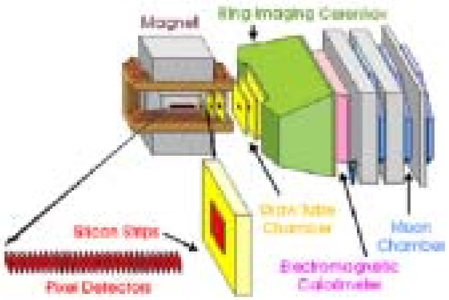
Reaction	$\mathcal{B}$ (B)($\times 10^{-6}$)	#	S/B	Parameter	Error
$B^- \to K_S \pi^-$	12.1	4,600	1		$<4^o$ +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	Theory errors
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B^o \to K^+ K^-$	17	18,900	6.6	Asymmetry†	0.020

† Can determine γ assuming d$\Leftrightarrow$s symmetry, therefore model dependent



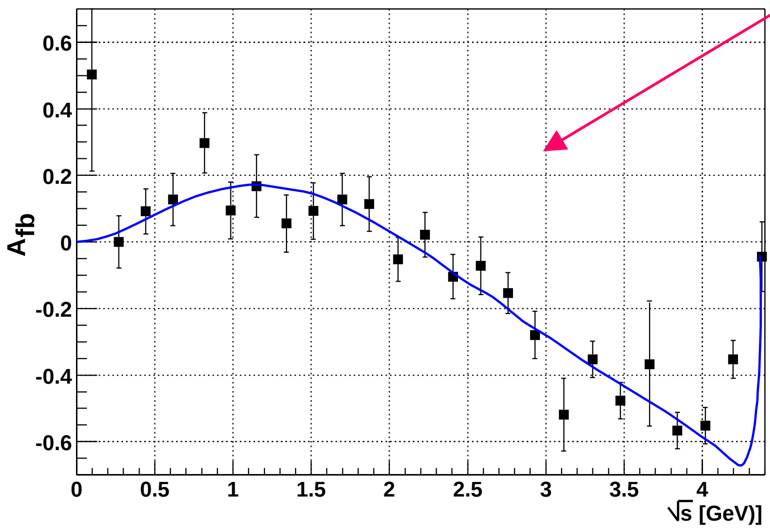
Physics Reach Rare Decays

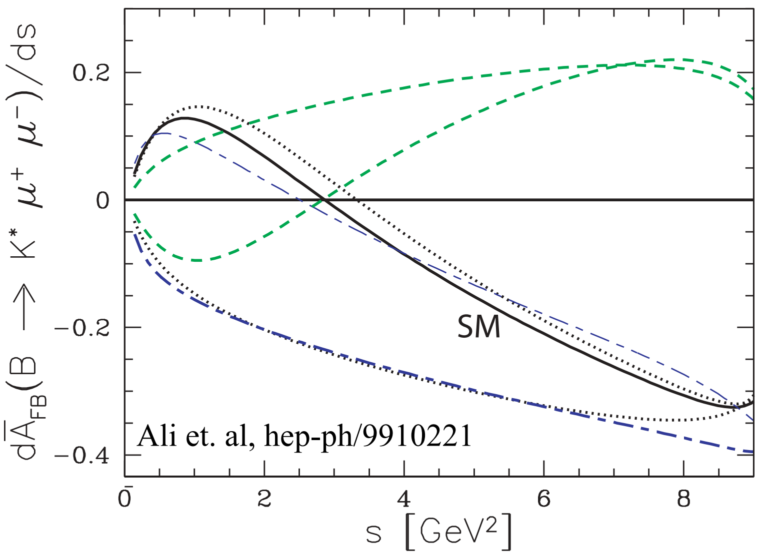
Reaction	B (10^{-6})	Signal	S/B	Physics
$B^o \to K^{*o}\mu^+\mu^-$	1.5	2530	11	polarization & rate
$B^- \to K^-\mu^+\mu^-$	0.4	1470	3.2	rate
$b \to s\mu^+\mu^-$	5.7	4140	0.13	rate: Wilson coefficents



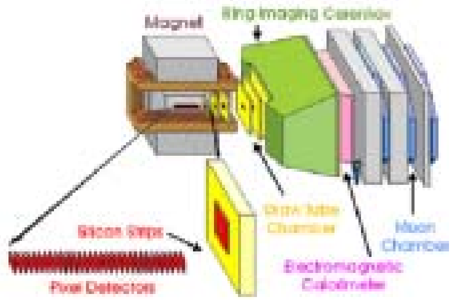
$B^o \to K^{*o}\mu^+\mu^-$ Polarization in $B^o \to K^{*o}\mu^+\mu^-$

- BTeV data compared to Burdman et al calculation





- One year for $K^*\ell^+\ell^-$, enough to determine if New Physics is present



Comparisons With Current e^+e^- B factories

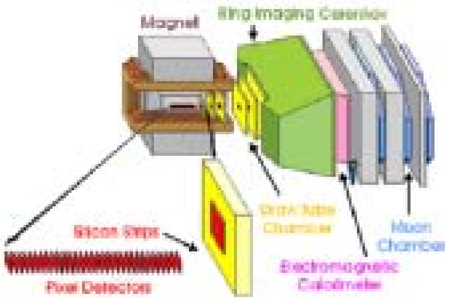
- Number of flavor tagged $B^o \rightarrow \pi^+ \pi^-$ ($\mathcal{B}$=0.45x10^{-5})

	L (cm^{-2}s^{-1})	σ	#B^o/10^{7}s	ε	εD^2	#tagged
e^+e^-	10^{34}	1.1 nb	1.1x10^8	0.45	0.26	56
BTeV	2x10^{32}	100μb	1.5x10^{11}	0.021	0.1	1426

- Number of $B^- \rightarrow \overline{D}^o K^-$ (Full product $\mathcal{B}$=1.7x10^{-7})

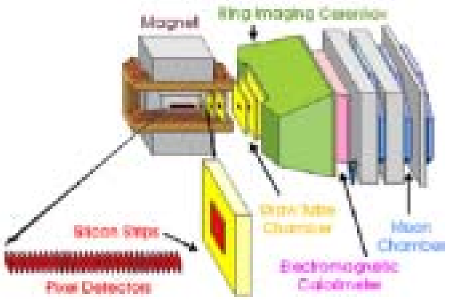
	L(cm^{-2}s^{-1})	σ	#B^o/10^{7}s	ε	#
e^+e^-	10^{34}	1.1 nb	1.1x10^8	0.4	5
BTeV	2x10^{32}	100μb	1.5x10^{11}	0.007	176

- B_s , B_c and Λ_b not done at Υ(4S) e^+e^- machines



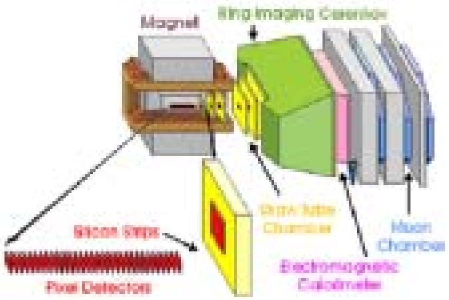
Reconstructed Events in New Physics Modes: Comparison of BTeV with B-factories

Mode	BTeV (10^7s)			B-fact (500 fb^{-1})		
	Yield	Tagged	S/B	Yield	Tagged	S/B
$B_s \to J/\psi \eta^{(\prime)}$	12650	1645	>15	-	-	
$B^- \to \phi K^-$	11000	11000	>10	700	700	4
$B^o \to \phi K_s$	2000	200	5.2	250	75	4
$B^o \to K^* \mu^+ \mu^-$	2530	2530	11	~50	~50	3
$B_s \to \mu^+ \mu^-$	6	0.7	>15	0		
$B^o \to \mu^+ \mu^-$	1	0.1	>10	0		
$D^{*+} \to \pi^+ D^o$, $D^o \to K\pi^+$	$\sim 10^8$	$\sim 10^8$	large	8×10^5	8×10^5	large



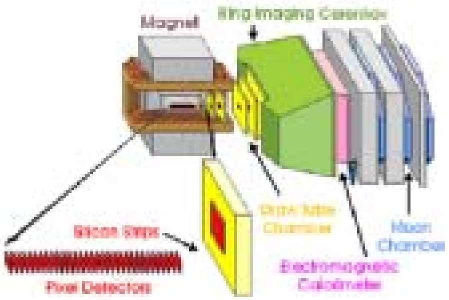
Super-KEK

- KEK-B plans for L=10^{35} in 2007, 10 x original design. However #'s in previous tables are still not competitive with BTeV
  - From the E2 report at Snowmass: Problems for the detector due to higher occupancies, trigger rates, synchrotron radiation, increased pressure in the interaction region & larger backgrounds at injection.
  - Problem areas include: silicon vertex detector, CsI(T*l*) EM calorimeter because it is slow, and Muon RPC's that already have dead-time losses



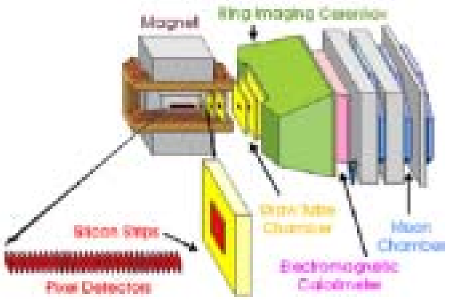
Advantages of BTeV with respect to LHCb

- BTeV has vertex detector in magnetic field which allows rejection of high multiple scattering (low p) tracks in the trigger
- BTeV is designed around a pixel vertex detector which has much less occupancy, and allows for a detached vertex trigger in the first trigger level.
  - Important for accumulation of large samples of rare hadronic decays and charm physics.
  - Allows BTeV to run with multiple interactions per crossing
- BTeV will have a much better EM calorimeter
- BTeV is planning to read out 5x as many b's/second



Comparisons with LHCb

- LHCb recently did very extensive changes to their design beyond their TDR; “LHCb light”
  - Changes
    - Vertex detector: reduced # of silicon strip detectors & silicon thickness from 300 $\rightarrow$220 μm
    - reduced # of tracking stations
    - allowed B field on interactions by removing magnet shielding plate; this puts B on RICH-1
    - Added high p_t only trigger, which helps on $B\rightarrow h^+h^-$
    - Allow multiple interactions in each crossing

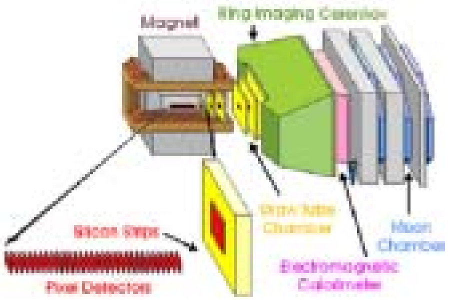


Status of LHCb Light Simulations

- Not enough background events run to understand background levels
- Efficiencies determined by making “reasonable” signal cuts
- Comparison (#’s from Nakada)

Final State	Old Eff (%)	New Eff (%)	Frac	BR (10^{-5})	Old Yield Untag	New Yield Untag	BTeV Yield scaled to BR
$D_s\,\pi^-$	.61	.31	.51	300	86000	43700	59000
$D_s\,K^-$	.54	.48	.89	23	6050	5375	5900

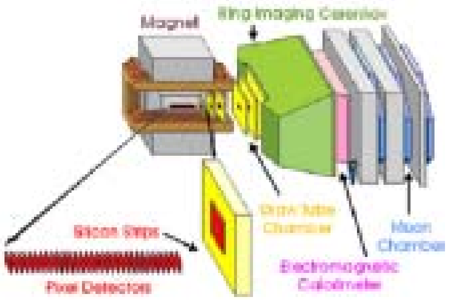
Why are these so different?



Specific Comparisons with LHC-b (TDR)

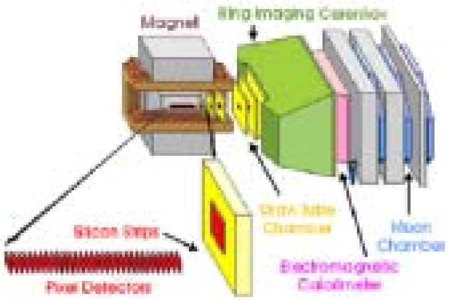
Yields in two final states

Mode	BR	BTeV		LHC-b	
		Yield	S/B	Yield	S/B
$B_s \rightarrow J/\psi\ \eta^{(\prime)}$	$1.0\text{x}10^{-3}$	12650	>15	-	-
$B^o \rightarrow \rho^+ \pi^-$	$2.8\text{x}10^{-5}$	5400	4.1	2140	0.8
$B^o \rightarrow \rho^o \pi^o$	$0.5\text{x}10^{-5}$	776	0.3	880	not known

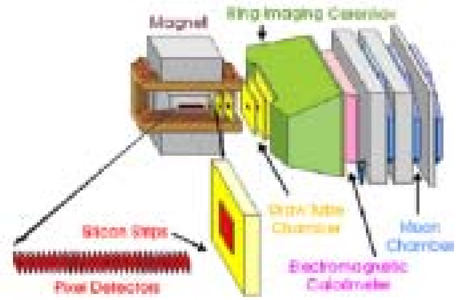


Conclusions

- Ed Witten at the ICFA Seminar at CERN, Oct. 2002 said: "I cannot guess where the biggest surprises will be, but there are many things to look forward to… we expect:
  - Expanding knowledge of CP violation in B decays
  - Increasingly sensitive probes of rare, flavor-violating processes"
- We are very excited about this experiment and are eager to get going

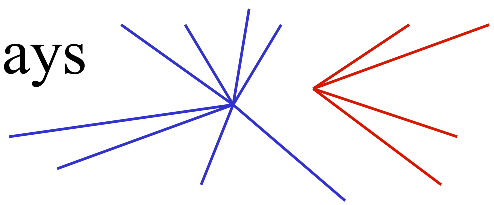


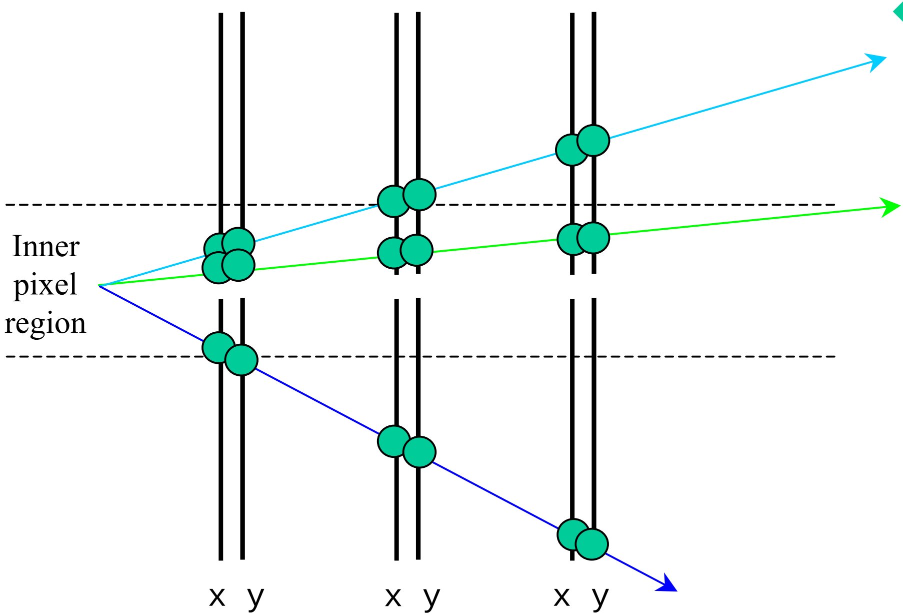
Backup Transparencies Follow



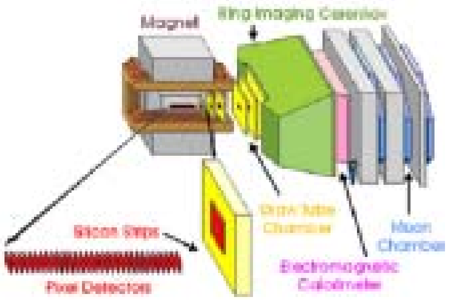
Pixel Trigger Overview

- Idea: find primary vertices & detached tracks from b or c decays





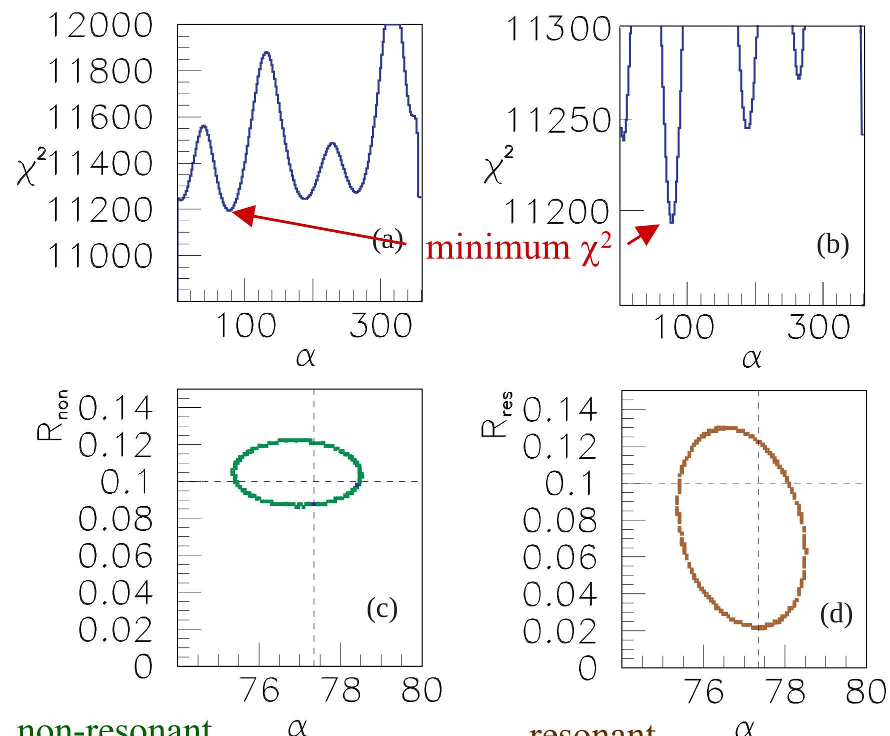
- Pixel hits from 3 stations are sent to an FPGA tracker that matches “interior” and “exterior track hits
- Interior and exterior triplets are sent to a farm of DSPs to complete the pattern recognition:
  - interior/exterior triplet matcher
  - fake-track removal



Our Estimate of Accuracy on α

- Simulation of $B^o \to \rho\pi$, (for 1.4×10^7 s) Yields in each channel fixed by simulation results, as are bkgrnds: Resonant (R_{res}) + Non-Resonant (R_{non}) ~ 0.4 of signal

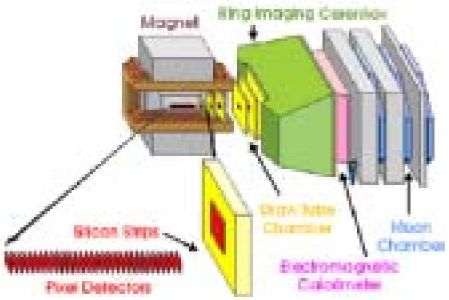
α (gen)	R_{res}	R_{non}	α (recon)	δα
77.3°	0.2	0.2	77.2°	1.6°
77.3°	0.4	0	77.1°	1.8°
93.0°	0.2	0.2	93.3°	1.9°
93.0°	0.4	0	93.3°	2.1°
111.0°	0.2	0.2	111.7°	3.9°
111.0°	0.4	0.2	110.4°	4.3°



non-resonant non-ρπ bkgrd

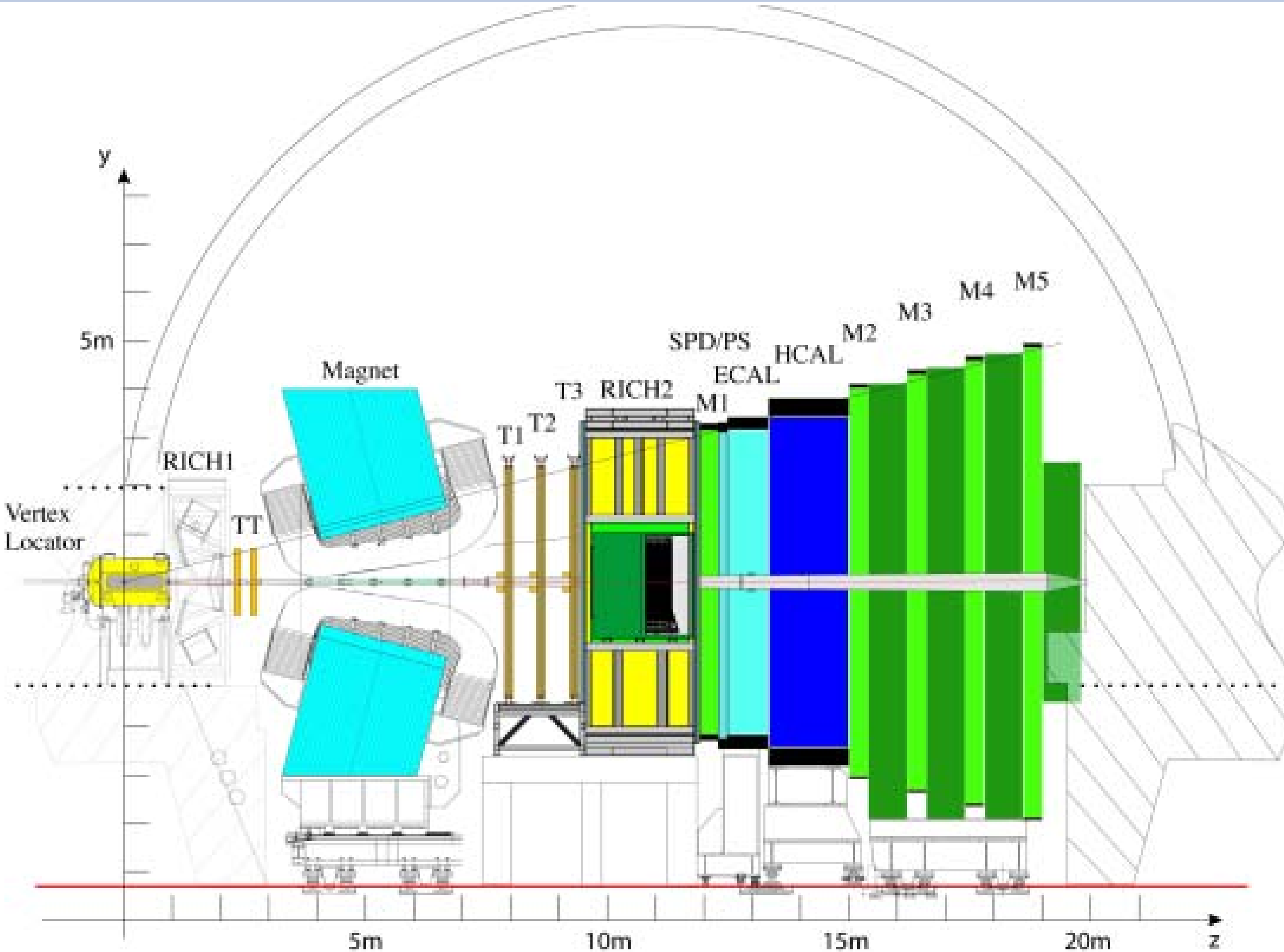
resonant non-ρπ bkgrd

1000 $B^o \to \rho\pi$ signal + backgrounds with input α=77.3°

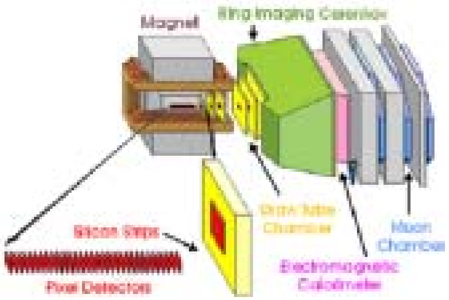


Magnet
Muon
Chamber
Electromagnetic
Calorimeter

LHCb Light



y
5m
Magnet
RICH1
Vertex
Locator
TT
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
M3
M4
M5
5m
10m
15m
20m
z



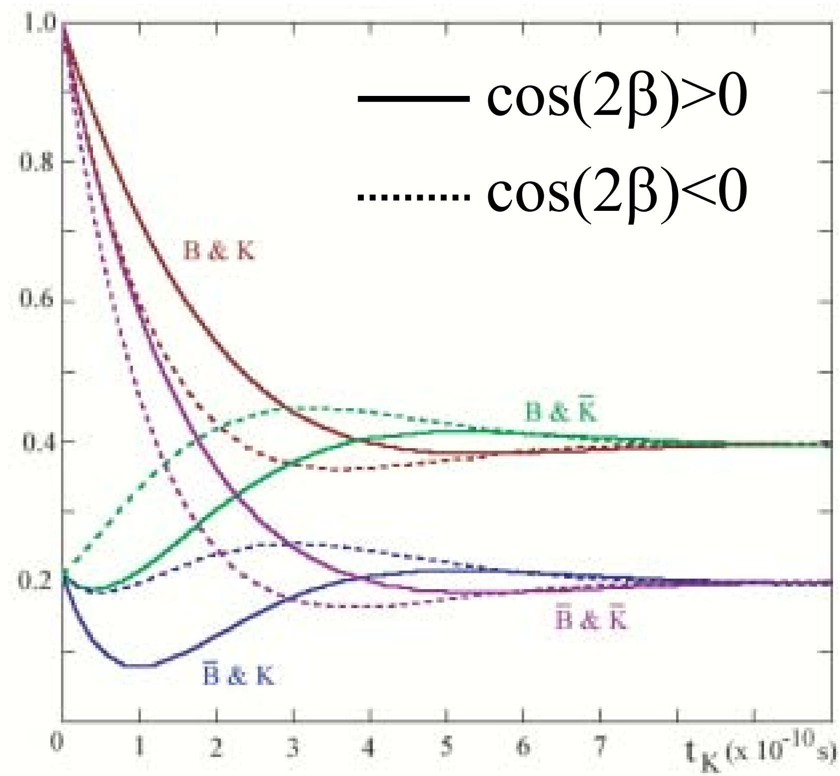
Decay Widths for $B^o \to \psi K^o$, $K^o \to \pi^+ \ell^- \nu$: Ambiguity resolution

$$
\begin{aligned}
&\Gamma(t_B, t_K) \propto \\
&e^{-\Gamma_B t_B}\{e^{-\gamma_s t_K}[1 \mp \sin(2\beta)\sin(\Delta m_B t_B)] \\
&+ e^{-\gamma_s t_K}[1 \pm \sin(2\beta)\sin(\Delta m_B t_B)] \\
&\pm(\mp)2e^{-\frac{1}{2}(\gamma_s+\gamma_L)t_K}[\cos(\Delta m_B t_B)\cos(\Delta m_K t_K) \\
&\qquad + \cos(2\beta)\sin(\Delta m_B t_B)\sin(\Delta m_K t_K)]\}
\end{aligned}
$$

top sign for B^o, bottom for $\overline{B}^o$

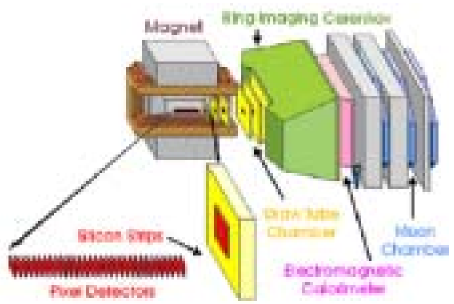
3rd line: 1st pair for $\pi^- \ell^+ \nu$ (K),

2nd pair for $\pi^+ \ell^- \nu$ (K)



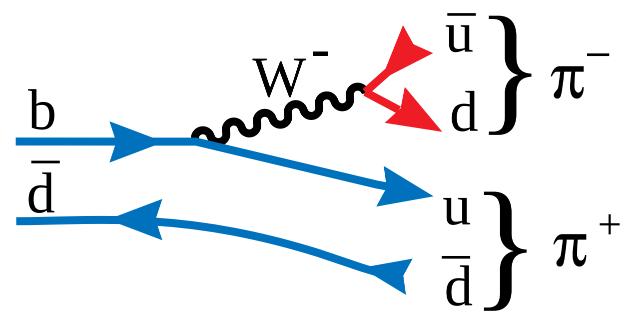
t_K integrated over t_B

- Low statistics, ~ 1/100 of $K_s \to \pi^+ \pi^-$
- CPT Tests: Like a double slit exp with B^o & K^o mixing

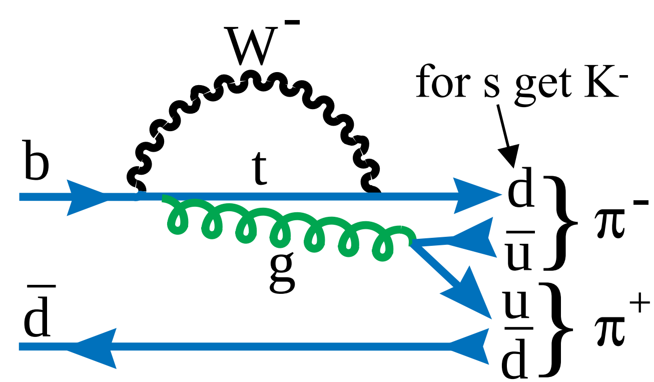


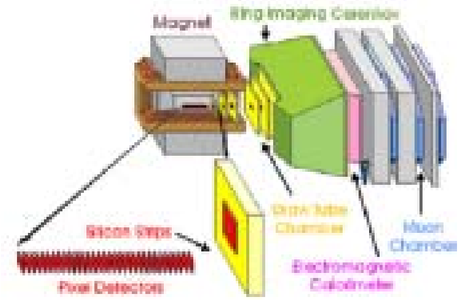
Problems With Measuring α Using $B^o \to \pi^+\pi^-$

- Using $B^o \to \pi^+\pi^-$ would be nice, but large Penguin term (CLEO+BABAR+BELLE):
  $\mathcal{B}(B^o \to \pi^+\pi^-) = (4.5 \pm 0.9)\mathrm{x}10^{-6}$
  $\mathcal{B}(B^o \to K^\pm\pi^\mp) = (17.3 \pm 1.5)\mathrm{x}10^{-6}$



- The effect of the Penguin must be measured in order to determine α. Can be done using Isopsin, but requires a rate measurements of $\pi^-\pi^o$ and $\pi^o\pi^o$ (Gronau & London). However, this is daunting.



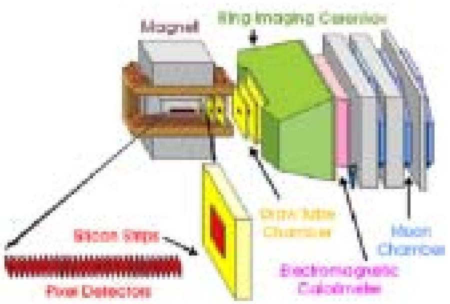


Ways of measuring γ

- May be easier to measure than α
- There are 4 ways of determining γ
  - Time dependent flavor tagged analysis of $B_s \to D_s K^-$
  - Rate difference between $B^- \to D^o K^-$ & $B^+ \to D^o K^+$

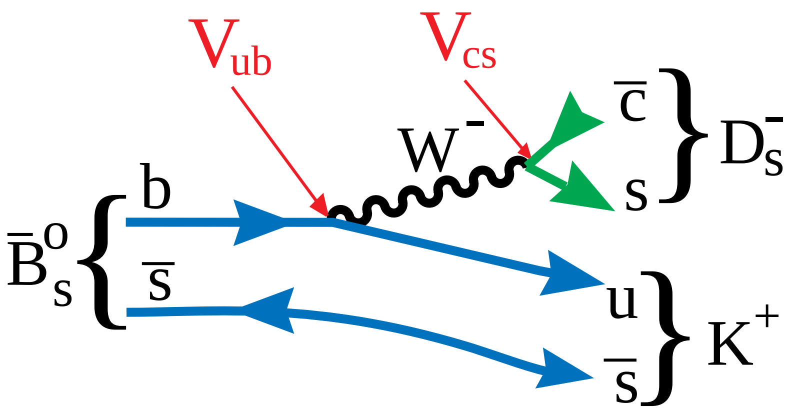
  Model independent

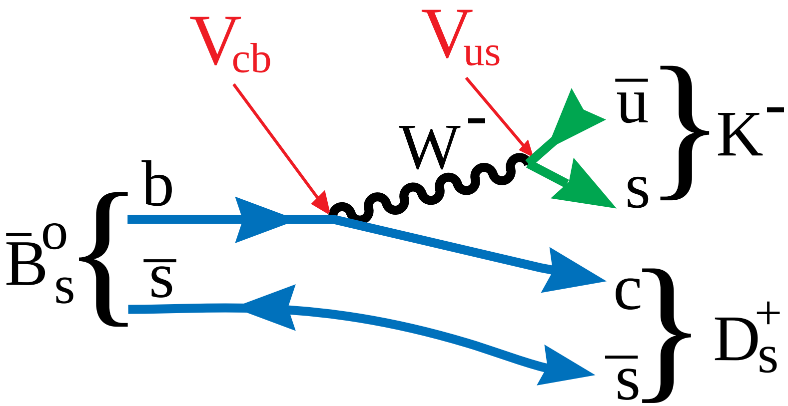
  - Rate measurements in $K^o\pi^\pm$ and $K^\pm\pi^\mp$ (Fleisher-Mannel) or rates in $K^o\pi^\pm$ & asymmetry in $K^\pm\pi^o$ (Neubert-Rosner, Beneke et al) . Has theoretical uncertainties but can be useful.
  - Use U spin symmetry d$\Leftrightarrow$s: measure time dependent asymmetries in both $B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$ (Fleischer).
  - Ambiguities here as well but they are different in each method, and using several methods can resolve them.

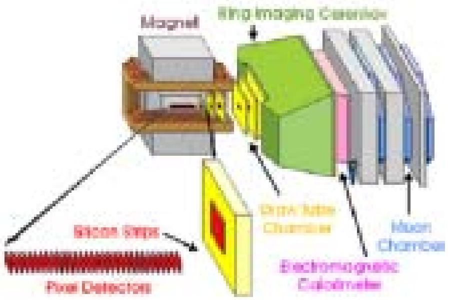


$B_s \rightarrow D_s^{\pm} K^{\mp}$ Decay processes

Diagrams for the two decay modes, $\mathcal{B} \sim 10^{-4}$ for each

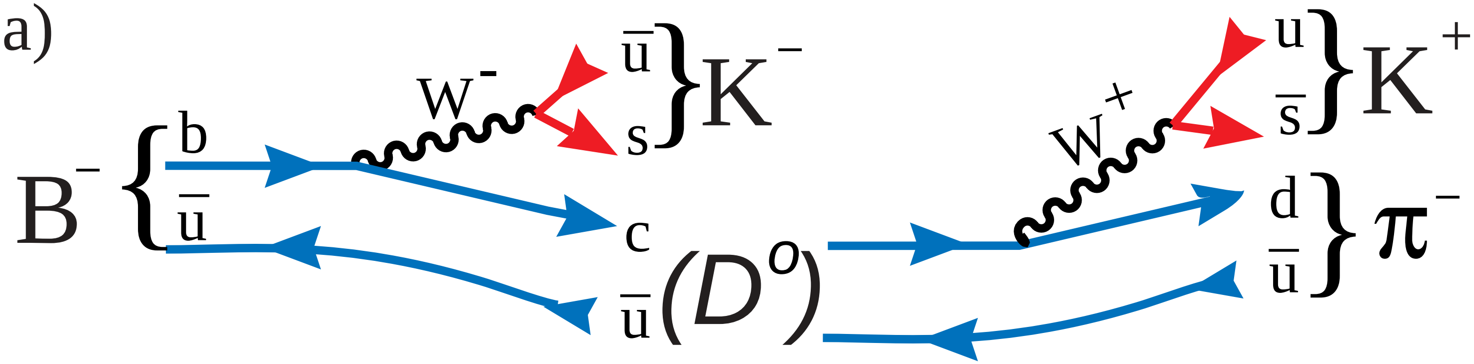






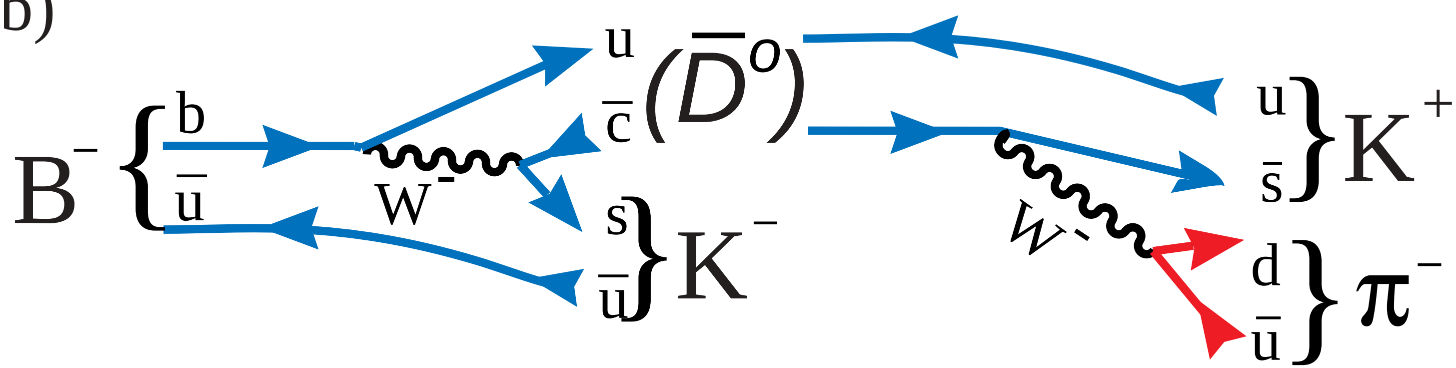
$B^- \to [K^+\pi^-]K^-$ Decay processes

a)

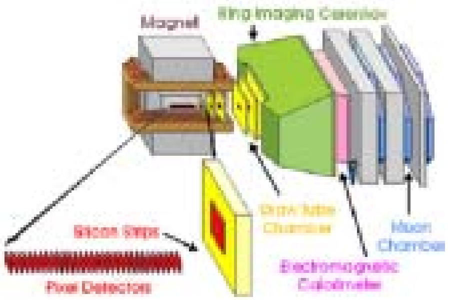


$\mathcal{B} \sim 1\text{x}10^{-7}$

b)

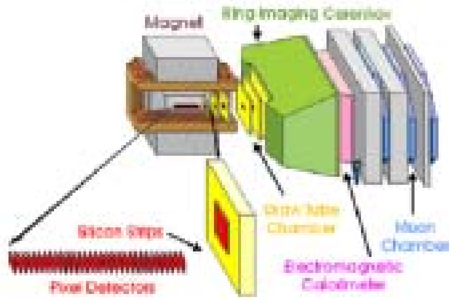


$\mathcal{B} \sim 0.7\text{x}10^{-7}$



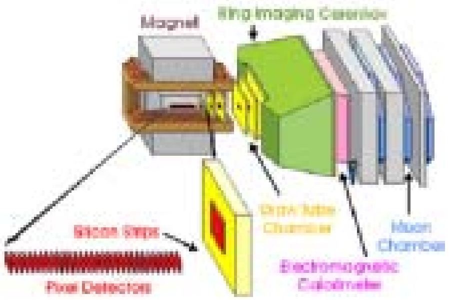
Precision CKM

- Can reconstruct entire CKM matrix knowing 4 parameters
  - Wolfenstein: A, λ, ρ, η all magnitudes
  - Aleksan, Kayser & London: β, γ, χ and χ', all phases
  - or β, γ, χ and $\lambda = 0.2205 \pm 0.0018$
- The latter strategy allows eventually precise ~few % values for CKM elements such as $|V_{ub}/V_{cb}|$ & $|V_{td}/V_{ts}|$



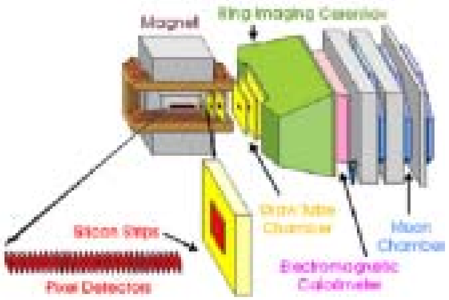
Super-BABAR

- Idea is to go to L=10^{36}. This would compete with BTeV in B^o & B^- physics, but not in B_s etc.
- **Problem areas**
  - **Machine:** Stu Henderson in his M2 review at Snowmass said: *"Every parameter is pushed to the limit-many accelerator physics & technology issues"*
  - **Detector:** Essentially all the BABAR subsystems would need to be replaced to withstand the particle densities & radiation load; need to run while machine fills continuously. Physics estimates are based on achieving same performance with brand new undeveloped technologies



Super-BABAR II

- Examples of Detector problems *(from the E2 summary)*
  - "To maintain the vertex resolution & withstand the radiation environment, pixels with a material budget of 0.3% X_o per layer are proposed. Traditional pixel detectors which consist of a silicon pixel array bump-bonded to a readout chip are at least 1.0% X_o. To obtain less material, monolithic pixel detectors are suggested. This technology has never been used in a particle physics experiment."
  - "As a drift chamber cannot cope with the large rates & large accumulated charge, a silicon tracker has been proposed. At these low energies track resolution is dominated by multiple scattering. Silicon technology is well tested but is usually used at this energy for vertexing, not tracking. Realistic simulations need to be performed to establish if momentum resolution as good as BABAR can be achieved with the large amount of material present in a silicon tracker."
  - "There is no established crystal technology to replace the CsI(Tl)."
  - "There is no known technology for the light sensor for the SuperDIRC."



Our View on Super-BABAR

- It would take a 10^{36} e^+e^- collider operating on the Υ(4S) to match the performance of BTeV on B^o & $B^{\pm}$ mesons, while there would be no competition on B_s, Λ_b, etc..
- There are serious technical problems for both the machine & the detector
- We believe the cost will far exceed that of BTeV. Recent subpanel mentions 500 M$